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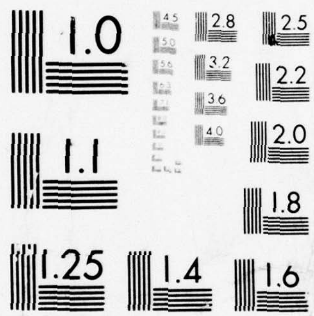

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DIRECTOR NOTES

In 1949 at the 14th Shock and Vibration Symposium Dr. Wernher von Braun gave a paper entitled "Vibration Problems in the V-2 and Similar Guided Missiles." He and his associates at Peenemuende recognized the importance of prevailing mechanical vibrations and how they might affect the success of the V-2 mission. Measurements were made during static firing tests and compared to initial flight vibration measured through trailing cables about one thousand feet long. These methods were crude by today's standards, but they accomplished the purpose. Dr. von Braun continued his efforts in this country and became the father of our own manned space program. His accomplishments are known to all of you. His recent death is a great loss to the scientific community.

This month the technical program committee for the 48th Shock and Vibration Symposium meets. Perhaps it is fitting in this, the year of his death, that the symposium will be held at the von Braun Civic Center in Huntsville, Alabama. It is also fitting that the U.S. Army Missile Research and Development Command is the host activity, since Dr. von Braun worked for the Army at Huntsville on the development of the rocket that placed the first U.S. satellite into orbit. It is expected that the technical program in Huntsville will be of high quality and will be a special tribute to this great space pioneer.

H.C.P.

EDITORS RATTLE SPACE

CONTINUING EDUCATION

Each month the DIGEST contains announcements of technical meetings and short courses. Typically, the purpose of the technical meetings is to disseminate technology derived from research and development programs. The short courses range from one-day seminars and workshops to programs as long as two weeks and are intended to provide basic education or to update a technology.

The growing number of successful short courses is of interest to me for the following reasons. First, many engineers are interested in specialized training in vibrations in order to be more effective in their work. Second, employers are willing to pay for this training because of the increased rewards associated with a good engineering staff.

Most short courses focus on a narrow area of technology, usually the participant benefits in proportion to his background knowledge. For this reason it is important that the engineer select a short course carefully. Titles and descriptions of short courses often seem to indicate similar content, when in fact, the approach used and the level of difficulty differ greatly. In addition, the experience of the lecturers varies from one source to another. To decide whether or not a course is worthwhile, the engineer should obtain a set of proceedings before signing up for the course or, if a proceedings is not available, he should look to the seminar brochure for descriptions of the background needed and of the level of difficulty of the material. Some short courses are designed to review new technology; the purpose of others is to draw together basic information about a broad segment of an area. Many of the speakers have extensive experience in practical applications, others know the basic material but have little experience in solving engineering problems. A speaker with industrial experience is usually willing to answer questions or give advice during coffee breaks or luncheons.

The benefits to the employer of employee attendance at a short course include better design and test results in a shorter period of time and with fewer mistakes. In addition, helpful tips from experienced lecturers can save many dollars and much time in design and development processes.

Short courses as a means of continuing education are thriving mostly because of the need for expanded technical knowledge for solving problems. Engineers are finding the short course an effective way to obtain this knowledge. The short course is increasing the productivity of our engineering departments and, indirectly, our manufacturing plants.

R.L.E.

TECHNIQUES FOR THE DESIGN OF HIGHLY DAMPED STRUCTURES

F.C. Nelson*

Abstract - The purpose of this review is to discuss three techniques for the design of highly damped structures, techniques which have proven successful for large-scale, low-frequency steel and concrete structures. The techniques are: the design of structural joints and interfaces to promote damping; the use of layers of viscoelastic material; and the employment of discrete dampers. The review explains how these techniques work and describes the ways in which they have been used.

DAMPING AT JOINTS AND INTERFACES

The damping of a built-up structure is largely a function of how it is joined rather than the material of which it is made. The energy dissipated in a joint that permits slip, such as a bolted joint, is much larger than that in a joint that prevents slip, such as a welded joint (Fig. 1).

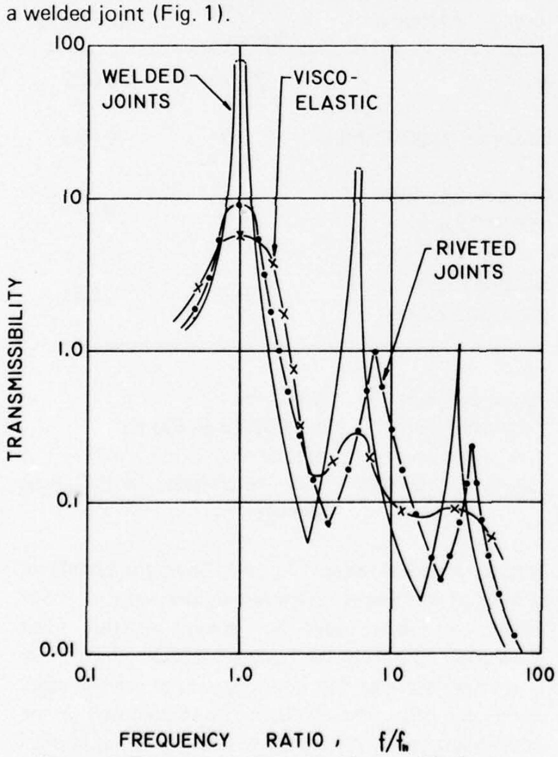

Figure 1. Transmissibilities for Various Methods of Joint Fabrication

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However, the use of bolted joints to promote damping can conflict with other structural requirements. A bolted joint designed for optimum damping is relatively loose and may degrade the stiffness of the structure. Joint slip also produces debris and can promote fretting corrosion. Nevertheless, if a highly damped structure is desired, the high damping potential of a bolted or riveted joint cannot be ignored. A quantitative assessment of damping due to relative slip at a bolted or riveted interface is not yet possible, but a qualitative understanding can be achieved with simple models.

When two dry surfaces are pressed together, they contact one another at a series of discrete localized regions. Friction is ascribed to the deformation and fracture of these contacting regions. When a cyclic tangential load is applied to an interface compressed by a constant normal force, three types of interaction can be identified.

(1) The contact regions undergo local cyclic plastic deformation but do not slip. This is called an unslipped joint. A small finite amount of energy is dissipated [1].
(2) The joint has regions of relative slip and regions of no relative slip. This is a partially slipped joint. As the amplitude of the tangential load is increased, the slip regions grow and coalesce until the joint is fully slipped [2].
(3) In a fully slipped joint, the magnitude of the friction force (F) can be predicted by Coulomb's law of friction

$$F = \mu N$$

where μ = coefficient of friction for the mating surfaces and N = normal force across the interface.

In a fully slipped joint, the damping force is a nonlinear function of relative velocity. If the nonlinearity is weak, the response to sinusoidal excitation can be assumed to be sinusoidal. Then the equivalent viscous damping coefficient (C_{eq}) is given by

$$C_{eq} = \frac{4\mu N}{\pi \Omega X} \tag{1}$$

where Ω is the forcing circular frequency and X is the slip amplitude. The energy dissipated per cycle (D) is

$$D = 4\mu NX \tag{2}$$

From equation (2), $D = 0$ when $N = 0$ (i.e., a free joint) and $D = 0$ when $X = 0$ (i.e., a locked joint). Hence, there is a joint tightness that maximizes D. Experiments indicate that X and N are approximately linearly related [3]; in particular,

$$X \approx -(X_F/N_L)\,N + X_F \tag{3}$$

where

X_F = slip amplitude of free joint

N_L = normal force required to lock the joint,

then maximum D occurs at $N = 1/2\ N_L$ and is equal to

$$D_{MAX} = \mu N_L\,X_F = F_L\,X_F \tag{4}$$

where F_L is the friction force required to lock the joint against full slip.

Optimum damping from a bolted joint is most likely if the joint preload is adjusted to one-half the value that locks the joint. Since, from equation (3), $N = 1/2\ N_L$ implies $X = 1/2\ X_F$, the slip amplitude can be adjusted to be one-half the slip of the free joint. A bolted joint that slips at all -- much less one for which $X = 1/2\ X_F$ -- may be unacceptable because of the resultant reduction in structural stiffness. Reduced structural stiffness can be somewhat overcome by inserting the joint into a redundant load path. The method used depends on the ingenuity of the designer; see Figure 2 for an example [4]

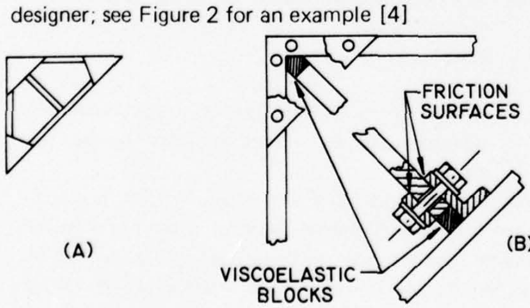


Figure 2. Reduction of Structural Stiffness
(A) Sample Structure
(B) Modification of Sample Structure to Increase Damping

Joints subjected to squeezing or rocking motions have also been investigated [5]. In this case the normal force is the time-varying independent variable. The tangential slip generated by normal force variation is usually small, and the joint damping is usually negligible. Damping can be increased to a useful level by either introducing interface lubrication or inserting such interfacial materials as polymer films or metal foils. Interface treatments can also increase the dynamic stiffness of the joint. The increase in stiffness is ascribed to an increase in the effective contact area between the mating surfaces; the increase in damping is ascribed to the oscillatory shearing of the oil or viscoelastic material. Of course, an interfacial layer that is too thick will govern the joint stiffness and produce a softer rather than a stiffer joint. An idea of what can be accomplished with this technique is shown in Table 1.

TABLE 1. Stiffness and Damping Results for a Non-sliding, Normally-Loaded, Single-Interface Joint* [6]

Interfacial Material	stiffness lb/μin.	loss factor
None	29.7	0.032
Lead Foil 0.004" thick	113.0	0.053
Polyethylene film 0.0034" thick	37.6	0.114
Silicone Fluid 106 Centistokes	30.8	0.071

*joint preload: 4,000 lbs
dynamic load: ± 3,000 lbs @ 100 Hz
metal surfaces: cast iron
surface roughness: 600 microinch, arithmetical average

Recent Japanese work [7] also shows the beneficial effects of interfacial layers but points out that interfacial lubrication does not always increase joint damping. Polyethelene gaskets 0.002" thick have been inserted into the bolted joints of inertial guidance unit [8]. The resonant transmissibility of the system was reduced from 25 to 15 at an input level of 5 g's. No detectable change occurred in either the fundamental frequency or the weight of the unit.

DAMPING BY VISCOELASTIC LAYERS

In addition to their value as interfacial layers in joints, viscoelastic materials can be coated on or inserted into the members of a built-up structure. Figure 3A illustrates the unconstrained or free layer treatment, in which the material is coated on the structure. As the base structure (usually a beam or plate) vibrates, the layer of viscoelastic material undergoes stretching and compression. One distinguishing feature of a viscoelastic material is that it can dissipate large amounts of mechanical energy -- in fact, as much as several orders of magnitude larger than common construction materials. Hence, a thin coating of such a material can significantly increase the damping of a composite structure. A study of the free layer treatment for beams was first made by Oberst in 1952, and design formulas are available [9]. For a given loss factor of the viscoelastic coating, maximum damping requires the stiffest coating possible; for this reason many of the polymers used as coatings are stiffened with various fillers.

Figure 3B illustrates the sandwich treatment, in which viscoelastic material is inserted into, or "sandwiched" between, two cover plates. When the structure vibrates, the material undergoes oscillatory shear,

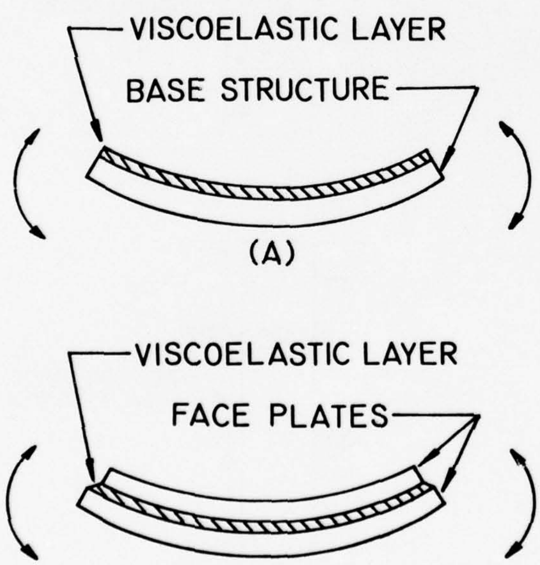


Figure 3. Damping Flexural Vibration with a Viscoelastic Material

thereby dissipating energy. In contrast to the free layer treatment, a high degree of damping can be achieved with a constrained soft viscoelastic material. Design formulas for constrained layers are also available [9]. This treatment is capable of producing more damping per unit of added weight than the free damping layer treatment.

The extent of damping of a viscoelastic material is a function of temperature and frequency; therefore, the temperature and frequency of the structure should be made the same as the peak damping region of the material. The temperature range associated with high damping can be broadened by using two or more immiscible polymers to make the viscoelastic material. Each component retains its damping peak; if the peaks are close in frequency, the useful damping range is extended to the distance between the peaks. As the high damping region is increased, however, the maximum damping value decreases. Effective temperature ranges of 200°F have been achieved with this mixing procedure [10].

The design of effective constrained viscoelastic layers requires careful attention to geometric factors. The viscoelastic layer must be able to store large amounts of energy before dissipating it. If the layer is soft, it deforms readily in shear but stores little energy and thus dissipates little energy. A rigid layer does not deform; hence it will neither store nor dissipate energy. Clearly then, an optimum layer stiffness exists for maximum energy dissipation. For proper design, the optimum stiffness of the viscoelastic layer must be known as a function of the type of structure (i.e., beam, plate, ring), the stiffnesses of the elastic layers, and the boundary conditions. Design guidelines for determining this optimum stiffness for multilayered symmetrical beams have been given [11]. See Figure 4 fore some typical results.

Laminated rings and shells have been studied [12], but design guidelines comparable to those given for multilayered symmetrical beams will probably not be available for curved structures until a finite element computer program with both elastic and viscoelastic elements is developed. The most advanced of these programs seems to be ASTRE, which has been discussed briefly in a recent monograph [13].

The technology of free and constrained viscoelastic layers has been successfully applied in the aerospace

industry to control vibration and noise transmission from broadband, high-frequency sources; these include free jets and turbulent boundary layers [14]. In this review, however, attention is focused on the application of this technology to large-scale, low-frequency structures.

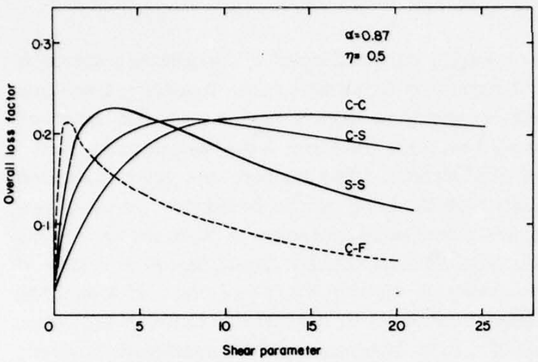


Figure 4. Effect of End Conditions on Loss Factor for Geometrically Similar Beams; S-S simply supported at each end; C-C clamped at each end; C-S clamped-simply supported; C-F cantilever. The shear parameter is proportional to the storage modulus of the viscoelastic layer

A constrained viscoelastic layer was used in a concrete structure in connection with the Barbican redevelopment in the City of London [15]. The structure was a continuous railway bridge deck with supports every 35 ft. The deck was made of prestressed concrete beams which have little inherent damping. A constrained viscoelastic layer was used to provide damping (see Figure 5). The damping material had to adhere to concrete and be able to accept wet concrete, which was poured to complete the sandwich. A bitumen reinforced with rubber latex proved successful. A single 0.25 in. layer of this material increased the damping ratio from 1.6% to 7.2% without significantly altering the natural frequency (16 Hz).

This technique has also been used in large-scale steel structures. In one structure -- a 70 ft X 56 ft X 42 ft sonic test facility -- the wall and roof girders were damped with constrained viscoelastic layers [16]. Figure 6 shows a cross section of the 100 in.-deep I-beams used as roof girders: the constraining layer was a 30 in.-deep I-beam. The treatment successfully controlled resonances in the 10 Hz to 60 Hz range. In another structure [17], a 79 ft-long composite concrete-steel bridge girder was treated with a 1/8 in.-thick layer of unconstrained viscoelastic material; the structural damping ratio was 5%, and the radiated noise due to impact was reduced by 13 dB(A).

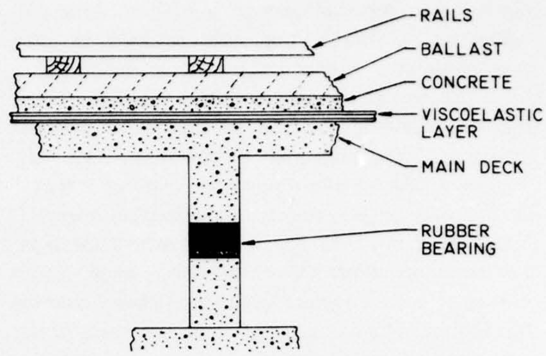


Figure 5. Damping Treatment of a Concrete Bridge Deck

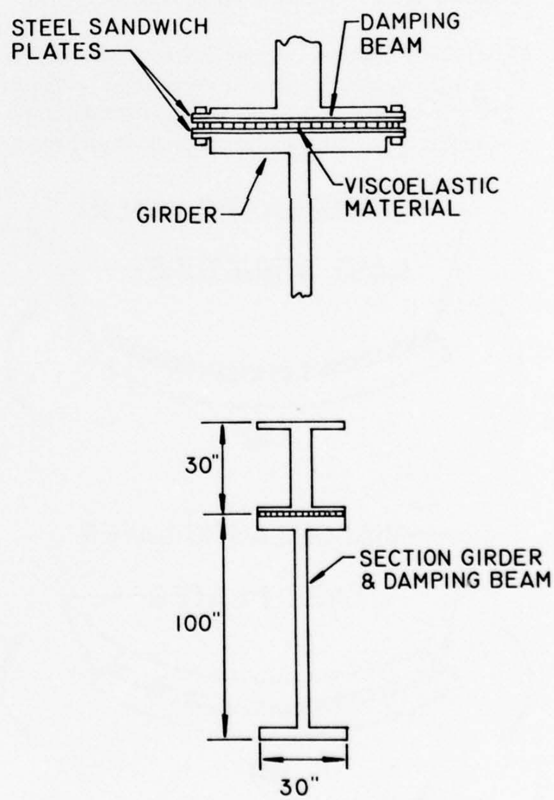


Figure 6. Damping Treatment of a Steel Girder

These examples, although not exhaustive, do illustrate a transfer of technology from the aerospace industry (lightweight, high-frequency structures) to the construction industry (large-scale, low-frequency structures). A similar transfer of damping layer technology to the design of rotating machinery and heat exchangers has been described [18].

DISCRETE DAMPERS

It is often convenient to incorporate a damper as a discrete link parallel to a main load path. This idea is an outgrowth of the longstanding practice of using discrete-parameter models for continuous structures. At present, discrete-parameter models of structures are generally formulated by a finite-element approach using matrix notation. The equations of motion take the form

$$[M]\left\{\ddot{x}\right\} + [C]\left\{\dot{x}\right\} + [K]\left\{x\right\} = \left\{f(t)\right\}$$

where [M], [C], and [K] are the n X n mass, damping, and stiffness matrices; $\{x\}$ and $\{f(t)\}$ are the n X 1 displacement and forcing function column matrices. The form of the discrete damping matrix [C] depends on whether it is derived from considerations of the physical mechanisms of damping or from a need for mathematical convenience. The various choices have been discussed in detail [19]. A number of recent suggestions for the use of discrete dampers and elastomeric elements to protect large-scale structures against vibration are described below.

Techniques for augmenting the damping of large structures is of particular interest to desginers of nuclear power plants. An increase in the damping of such structures can significantly improve their ability to withstand seismic excitation. Damping augmentation could be far more economical than the alternatives of a very rigid structure or the use of large-scale base-isolators to introduce flexibility.

Damping links in the form of viscoelastic shear dampers have been used in the 110-story World Trade Center Building in New York City. About 10,000 of these dampers were used as links between the floor trusses and the building frame (see Figure 7). Their purpose is to limit wind-induced vibration of the buildings in the 0.1 Hz range. The design of these dampers has been described [20].

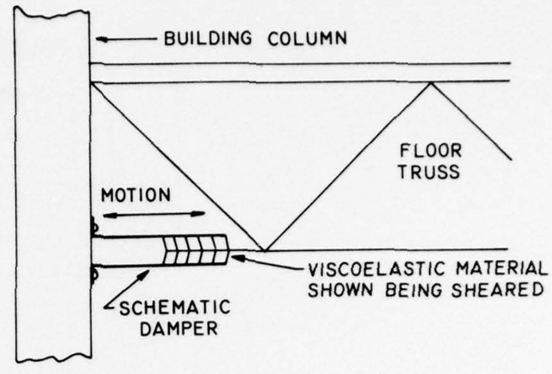


Figure 7. Location of Viscoelastic Shear Damper in a Floor Truss

Zeller [21] has reported on the use of butyl blocks between the floor, floor trusses, and frame of a four-story, steel-frame building. The blocks increased the damping ratio of the building from 2% to 6% at the fundamental resonance of 3.69 Hz. The use of elastomeric elements to provide vibration isolation for buildings has been discussed more generally by Waller [22]. He describes the design of a series of laminated steel plate and natural rubber blocks to support a six-story apartment building. The largest block is 24 in. X 20 in. X 11 5/16 in. and carries a vertical load of 216 tons. The fundamental frequency for vertical vibration in 7 Hz. No information is given on damping. A broad survey of the field of building vibration has recently been presented [23].

It has been suggested [24] that metal links in which plastic deformation occurs when energy is absorbed can be used to control the seismic response of large structures. Figure 8 shows a design in which the hysteresis associated with cyclic elastic-plastic bending and twisting of a rectangular steel bar absorbs energy. This design has been proposed as a base isolation system for a 10-story steel-frame building having a dead wieght of 30 X 10^6 lbs and a fundamental frequency of 1.25 Hz.

Robinson [25] has suggested a device that absorbs energy by the cyclic extrusion of lead (see Figure 9). These extrusion dampers have a nearly square hysteresis loop and have been tested to a force level of 200 kN and a stroke of 26 cm.

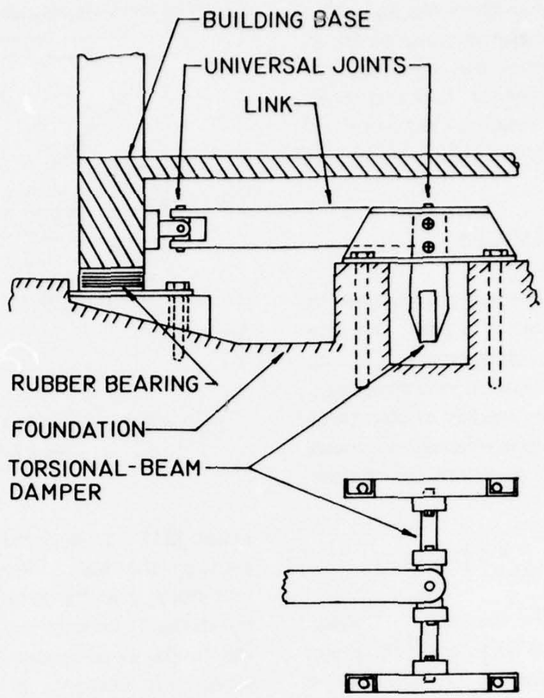


Figure 8. Torsional-Beam Hysteretic Damper

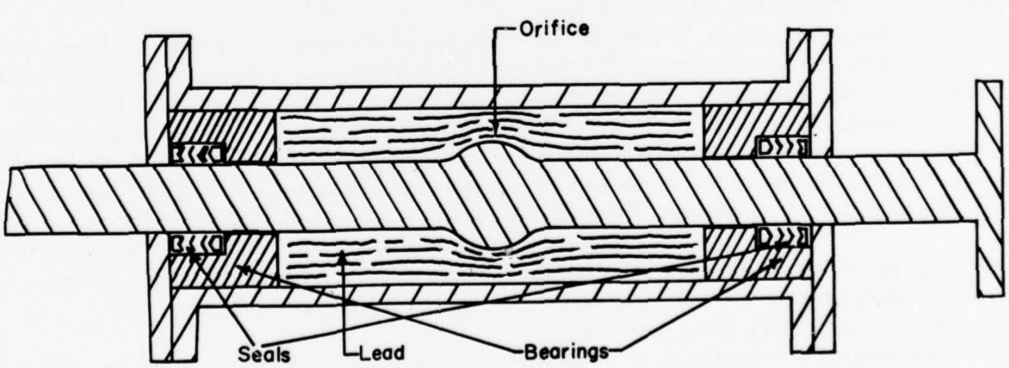


Figure 9. Longitudinal Section of a Bulged-Shaft Extrusion Energy-Absorber

high-capacity hydraulic dampers have been designed and field tested [26]. The dampers were installed and tested on a spherical gas tank with a diameter of 36 m and a weight of 1,190 tons. The dampers increased the damping ratio from 6.7% to 10.5% without significantly changing the fundamental frequency of 1.5 Hz. The configuration of these oil-filled dampers is shown in Figure 10.

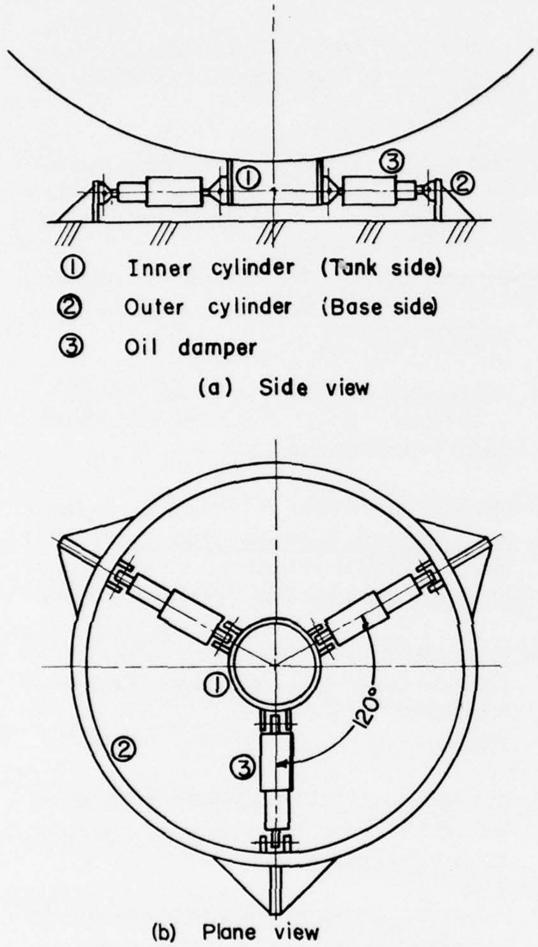
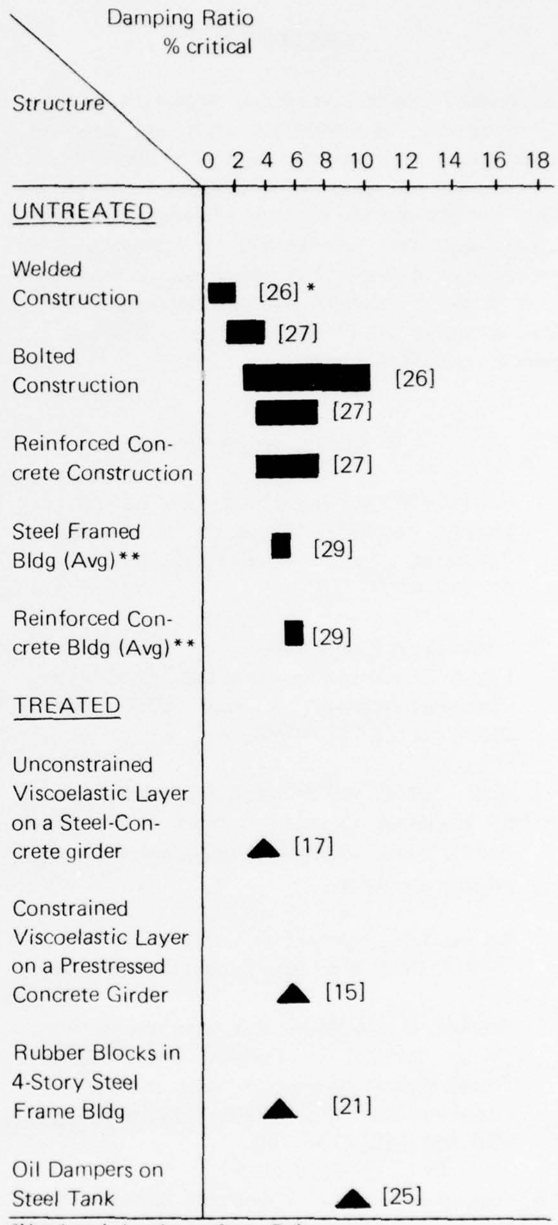


Figure 10. Oil Damper Installation

Thus a number of concepts have been suggested and tested. One measure of the value of these concepts is the extent to which they increase the expected inherent damping of untreated structures. Table 2 compares some of the concepts described in this article with the damping levels expected in aerospace structures [27], nuclear power plant structures [28], and buildings [29]. Other measures of value of additive dampers are their reliability and life. It is hoped that the originators of these

Table 2. Comparison of Damping Concepts



*Numbers in brackets refer to References

**Reference 29 reports that modal damping is a linearly increasing function of input spectral velocity. These points are for a least squares fit of the data at a spectral velocity of 25 in./sec; the lower bound of the data at 25 in./sec is 3% damping.

concepts will continue to report on the performance of their units, so that designers can select the proper concept for a given situation.

CONCLUSION

Much experience in ways for augmenting the damping of large-scale, low-frequency steel and concrete structures is now available. New concepts continue to be suggested. In time, comparative performance data will identify the concepts of lasting value, and the designer will have an additional practical and proven way to protect large structures against vibration. Rather than taking whatever damping a structure offers, he will be able to design a structure to have the damping he wants.

REFERENCES

1. Rogers, P.F. and Boothroyd, G., "Damping at Metallic Interfaces Subjected to Oscillating Tangential Loads," ASME Paper No. 74-WA/PROD-9 (1974).

2. Metherell, A.F. and Diller, S.V., "Instantaneous Energy Dissipation Rate in a Lap Joint-Uniform Clamping Pressure," J. Appl. Mech., Trans. ASME, pp 123-128 (1968).

3. Earles, S.W.E. and Beards, C.F., "Some Aspects of Frictional Damping Applied to Vibrating Beams," Intl. J. Mach. Tool Des. Res., 10, pp 123-131 (1970).

4. Beards, C.F., "Structural Damping by Slip in Joints," Shock Vib. Dig., 7, pp 113-119 (1975).

5. Andrew, C., Cockburn, J.A., and Waring, A.E., "Metal Surfaces in Contact Under Normal Forces: Some Dynamic Stiffness and Damping Characteristics," Instn. Mech. Engr. Proc., 182 (3K), pp 72-100 (1967-68).

6. Fagerstrom, W.B., "Dynamic Stiffness and Damping of Machined Interfaces and Their Effect on the Dynamic Stiffness of a Structure," Ph.D. Thesis, Univ. Wisconsin (1972).

7. Ito, Y. and Masuko, M., "Study on the Damping Capacity of Bolted Joints - Effects of the Joint Surface Conditions," Bull. JSME, pp 319-326 (Mar 1975).

8. Nelson, F.C. and Sullivan, D.F., "Damping in Joints of Built-Up Structures," Proc. Inst. Environ. Sci. (1976).

9. Cremer, L., Heckl, M., and Ungar, E.E., Structure - Borne Sound, Springer-Verlag, p 221 (1973).

10. Nashif, A.D. and Cannon, C.M., "Wide-Temperature-Range Free-Layer Damping Treatments," J. Acoust. Soc. Amer., 43, p 1184 (1968).

11. Grootenhuis, P., "The Control of Vibrations with Viscoelastic Materials," J. Sound Vib., pp 421-433 (1970).

12. DiTaranto, R.A., "Free and Forced Vibration of a Laminated Ring," J. Acoust. Soc. Amer., 53, pp 748-757 (1973).

13. Nelson, F.C. and Greif, R., "Damping," in Shock and Vibration Computer Programs, (1975), Shock and Vibration Information Center, Office of Naval Research, Washington, D.C. (1975).

14. Jones, D.I.G. and Trapp, W.J., "Influence of Additive Damping on Resonance Fatigue of Structures," J. Sound Vib., 17, pp 157-185 (1971).

15. Grootenhuis, P., "The Attenuation of Noise and Ground Vibrations from Railways," J. Environ. Sci., pp 14-19 (Apr 1967).

16. Nelson, F.C., "The Use of Viscoelastic Material to Damp Vibration in Buildings and Large Structures," AISC Engr. J., pp 71-78 (Apr 1968).

17. Kirschner, F., Salmon, V., and Oleson, S.K., "Viscoelastic Damping for Rapid Transit Structures," 5th Intl. Congr. Acoustics, Liege (1965).

18. Jones, D.I.G., "High Temperature Damping of Dynamic Systems," Shock Vib. Dig., 8 (10), pp 3-16 (1976).

19. Nelson, F.C. and Greif, R., "On the Incorporation of Damping in Large, General-Purpose Computer Programs," Nucl. Engr. Des., 37, pp 65-72 (1976).

20. Mahmoodi, P., "Structural Dampers," ASCE J. Struc. Div., pp 1661-1672 (1969).

21. Zeller, E., "Dynamic Tests on an Actual Building Mounted with a New Damper System," Proc. 5th World Congr. Earthquake Engr., Rome, pp 1517-1521 (1974).

22. Waller, R.A., Building on Springs, Pergamon Press (1969).

23. Ungar, E.E., Dym, C.L., and White, R.W., "Prediction and Control of Vibration in Buildings," Shock Vib. Dig., 8 (9), pp 13-24 (Sept 1976).

24. Skinner, R.I., Beck, J.L., and Bycroft, G.N., "A Practical System for Isolating Structures from Earthquake Attack," Intl. J. Earthquake Engr. Struc. Dynam., 3 (3), pp 297-309 (1975).

25. Robinson, W.H. and Greenbank, L.R., "An Extrusion Energy Absorber Suitable for the Protection of Structures during an Earthquake," Intl. J. Earthquake Engr. Struc. Dynam., 4, pp 251-259 (1976).

26. Kunieda, M. and Sakurai, H., "Application of the Oil Damper to Spherical Tank in Earthquake-Resistant Design," Bull. JSME, 18 (122), pp 807-812 (1975).

27. "Structural Vibration Prediction," NASA SP-8050, p 23 (1970).

28. "Damping Values for Seismic Design of Nuclear Power Plants," Regulatory Guide 1.61, U.S. Atomic Energy Commission (Oct 1973).

29. Hart, G.C. and Vasudevan, R., "Earthquake Design of Buildings: Damping," ASCE J. Struc. Div., 101 (ST1), pp 11-30 (1975).

LITERATURE REVIEW

survey and analysis of the Shock and Vibration literature

The monthly Literature Review, a subjective critique and summary of the literature, consists of two to four review articles each month, 3,000 to 4,000 words in length. The purpose of this section is to present a "digest" of literature over a period of three years. Planned by the Technical Editor, this section provides the DIGEST reader with up-to-date insights into current technology in more than 150 topic areas. Review articles include technical information from articles, reports, and unpublished proceedings. Each article also contains a minor tutorial of the technical area under discussion, a survey and evaluation of the new literature, and recommendations. Review articles are written by experts in the shock and vibration field.

This issue of the DIGEST features the last of two four-part review articles published is serial form. J.J. Jensen and N.F. Madsen of the Department of Ocean Engineering at Lyngby Denmark compare beam models for ship hull vibration calculation. L.H. Chen and M. Pierucci of General Dynamics Electric Boat Division review hydrodynamically applied forces as they apply to the underwater fluid-structure interaction problem.

A REVIEW OF SHIP HULL VIBRATION
PART IV: COMPARISION OF BEAM MODELS

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Abstract - This paper is a review of the analytical and numerical tools used to calculate hull vibrations. Mathematical Models were described in the first part The second part on Modeling of Physical Phenomena contained descriptions of mathematical models of the hull. Numerical determination of the equations of motion was discussed in the third part -- Methods of Solution. The fourth part, Comparison of Beam Models, is a review of methods used to solve the equations of motion; an example problem illustrates various principles.

Beam models have been used to calculate vertical vibration on a 340,000 tdw tanker [87]. The double beam model was used to represent the transverse deflection, which contributes to the vibratory behavior of the hull for higher modes. The main components of the tanker are shown in Figure 4.

Longitudinal and transverse bulkheads divide the hull of the tanker; each section contains a number of web frames. These features are represented in the model by two vertical Timoshenko beams connected by springs. Beam number one represents the longitudinal bulkheads (abbreviated L. Bhd.) and beam number two the side shells. The distributions of mass and stiffness, related to the two beams, are shown in Figure 5. The transverse deflection in the wing tank is shown in the figure; only modes symmetrical about the lateral plane are considered. Connecting springs were used to model the stiffness in the vertical direction of the transverse bulkheads.

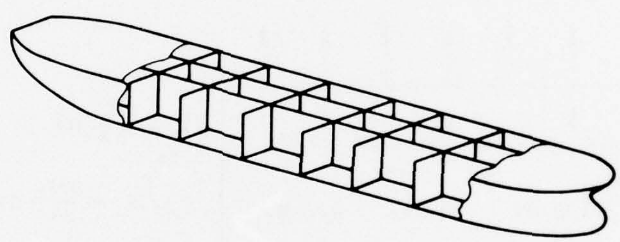

Figure 4. Main Components of a Large Tanker

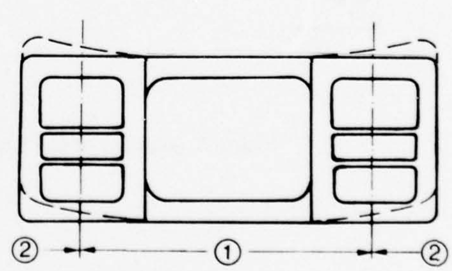

Figure 5. Vibration mode with symmetrical deformation of the cross section. The mass and stiffness distributions of areas labelled 1 and 2 are related to beam number one and two, respectively.

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The special theory for a double beam model [47] was used to calculate the virtual added mass. Three-dimensional effects were accounted for with the empirical formula suggested by Townsin [128]; the empirical formula of Prohaska [105] was used for reduced depth.

The procedure incorporates several numerical methods. A segment of the double beam model and the forces acting on it are shown in Figure 6.

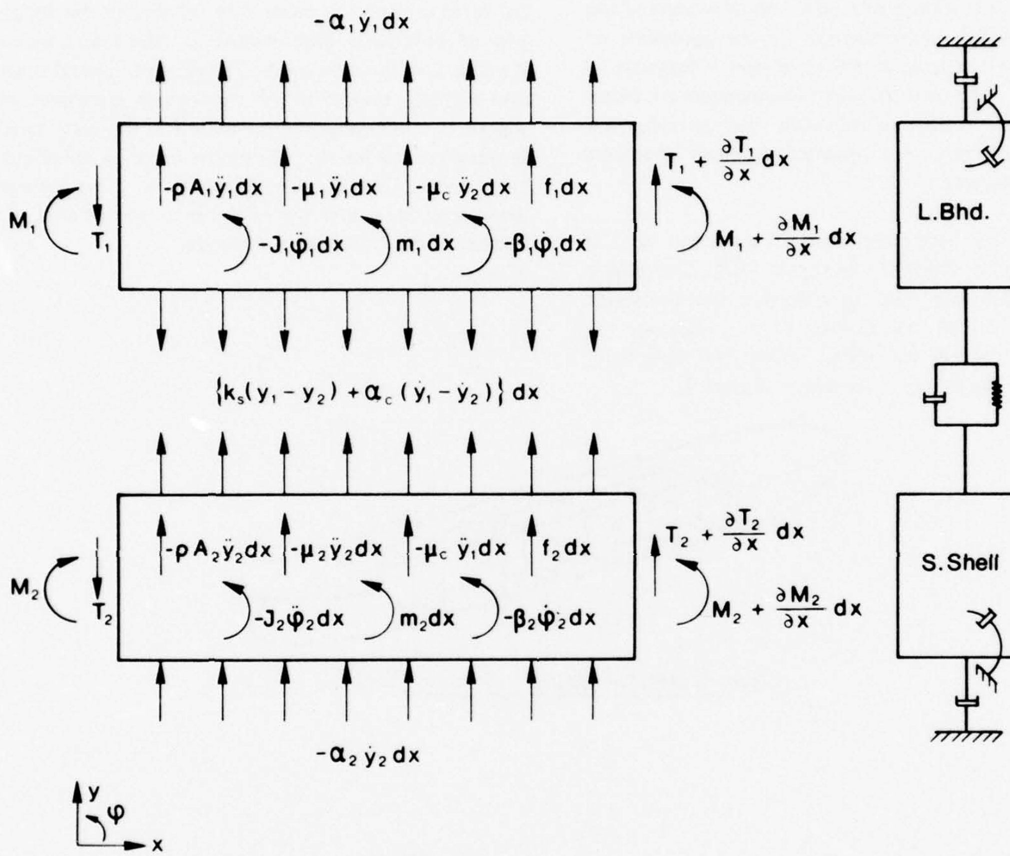

Figure 6. Segment of the Double Beam Model Showing the Acting Forces

Figure 6 and the constitutive equations for the moments M_ν and the shear forces T_ν are used to obtain the equations of motion.

$$M_\nu = EI_\nu \phi' \qquad T_\nu = kGA_\nu (y'_\nu - \phi_\nu) \qquad \nu = 1, 2 \tag{26}$$

$$\begin{aligned}
&(EI_1\phi_1')' + kGA_1(y_1' - \phi_1) = J_1\ddot{\phi}_1 + \beta_1\dot{\phi}_1 - m_1 \\
&[kGA_1(y_1' - \phi_1)]' = \alpha_1\dot{y}_1 - k_s(y_2 - y_1) - \\
&\qquad \alpha_c(\dot{y}_2 - \dot{y}_1) + (\rho A_1 + \mu_1)\ddot{y}_1 + \mu_c\ddot{y}_2 - f_1 \\
&(EI_2\phi_2')' + kGA_2(y_2' - \phi_2) = J_2\ddot{\phi}_2 + \beta_2\dot{\phi}_2 - m_2 \\
&[kGA_2(y_2' - \phi_2)]' = \alpha_2\dot{y}_2 - k_s(y_1 - y_2) - \\
&\qquad \alpha_c(\dot{y}_1 - \dot{y}_2) + (\rho A_2 + \mu_2)\ddot{y}_2 + \mu_c\ddot{y}_1 - f_2
\end{aligned} \tag{27}$$

The connecting spring stiffness per unit length is K_s.

The steady-state response induced by the harmonic forces and moments is represented as:

$$\begin{aligned}
f_\nu &= f_{1\nu}\cos\Omega t + f_{2\nu}\sin\Omega t \qquad \nu = 1, 2 \\
m_\nu &= m_{1\nu}\cos\Omega t + m_{2\nu}\sin\Omega t
\end{aligned} \tag{28}$$

These equations can be written as

$$\begin{aligned}
y_\nu &= y_{1\nu}(x)\cos\Omega t + y_{2\nu}(x)\sin\Omega t \\
&\qquad \nu = 1, 2 \\
\phi_\nu &= \phi_{1\nu}(x)\cos\Omega t + \phi_{2\nu}(x)\sin\Omega t
\end{aligned} \tag{29}$$

The set of four partial differential equations is reduced to a set of eight ordinary differential equations by substituting equations (28) and (29) into equation (27).

The first n-2 free vibration modes ($\overset{1}{u}_i, \overset{1}{v}_i, \overset{2}{u}_i, \overset{2}{v}_i$; i = 1, 2, . . ., n-2) are calculated for each beam by successive iteration. Linear combinations of the first n-2 single beam modes and the two rigid body modes are used to approximate the vibration modes of the coupled system. (The rigid body modes are included because translation and rotation between the beams are possible vibration modes.)

$$\begin{aligned}
y_{11} &= \sum_{i=1}^{n} a_{2i-1}\overset{1}{u}_i & y_{21} &= \sum_{i=1}^{n} a_{2i+2n-1}\overset{1}{u}_i \\
\phi_{11} &= \sum_{i=1}^{n} a_{2i-1}\overset{1}{v}_i & \phi_{21} &= \sum_{i=1}^{n} a_{2i+2n-1}\overset{1}{v}_i \\
y_{12} &= \sum_{i=1}^{n} a_{2i}\overset{2}{u}_i & y_{22} &= \sum_{i=1}^{n} a_{2i+2n}\overset{2}{u}_i \\
\phi_{12} &= \sum_{i=1}^{n} a_{2i}\overset{2}{v}_i & \phi_{22} &= \sum_{i=1}^{n} a_{2i+2n}\overset{2}{v}_i
\end{aligned} \tag{30}$$

Orthogonality conditions for the normalized modes for a vibrating Timoshenko beam are used to reduce the differential equations to 4n linear algebraic equations. The coefficients a_j in the linear combinations (equations 30) are unknowns. This algebraic system is written in matrix form in equation (31).

$$\left[-\Omega^2\begin{bmatrix}[M] & [0] \\ [0] & [M]\end{bmatrix} + \Omega\begin{bmatrix}[0] & [C] \\ [C] & [0]\end{bmatrix} + \begin{bmatrix}[K] & [0] \\ [0] & [K]\end{bmatrix}\right]\begin{Bmatrix}\{A_c\} \\ \{A_s\}\end{Bmatrix} = \begin{Bmatrix}\{F_c\} \\ \{F_s\}\end{Bmatrix} \tag{31}$$

The unknown a_j are assembled in the vector $\{\{A_c\}, \{A_s\}\}^T$. The load vector is denoted by $\{\{F_c\}, \{F_s\}\}^T$. The subscripts c and s refer to cosine and sine components.

For free, undamped vibrations, equation (31) reduces to the symmetric and semi-definite eigenvalue problem shown in equation (32).

$$[[K] - \omega^2\,[M]]\,\{A\} = \{0\} \tag{32}$$

The mass matrix [M] (2n x 2n) is identified as

$$M_{2i-1,\,2j-1} = \delta_{ij} + \int_0^L \mu_1 \overset{1}{u}_i \overset{1}{u}_j dx \; ; \quad M_{2i-1,\,2j} = \int_0^L \mu_c \overset{2}{u}_i \overset{1}{u}_j dx$$

$$M_{2i,2j} = \delta_{ij} + \int_0^L \mu_2 \overset{2}{u}_i \overset{2}{u}_j dx \; ; \quad M_{2i,\,2j-1} = \int_0^L \mu_c \overset{1}{u}_i \overset{2}{u}_j dx$$

the damping matrix [C] as

$$C_{2i-1,\,2j-1} = -\int_0^L \left\{ \beta_1 \overset{1}{v}_i \overset{1}{v}_j + (\alpha_1 + \alpha_c) \overset{1}{u}_i \overset{1}{u}_j \right\} dx \qquad C_{2i-1,\,2j} = \int_0^L \alpha_c \overset{2}{u}_i \overset{1}{u}_j dx$$

$$C_{2i,\,2j} = -\int_0^L \left\{ \beta_2 \overset{2}{v}_i \overset{2}{v}_j + (\alpha_1 + \alpha_c) \overset{2}{u}_i \overset{2}{u}_j \right\} dx \qquad C_{2i,\,2j-1} = \int_0^L \alpha_c \overset{1}{u}_i \overset{2}{u}_j dx$$

the stiffness matrix [K] as

$$K_{2i-1,\,2j-1} = \overset{1}{\omega}{}_i^2 \, \delta_{ij} + \int_0^L k_s \overset{1}{u}_i \overset{1}{u}_j dx \; ; \qquad K_{2i-1,\,2j} = -\int_0^L k_s \overset{2}{u}_i \overset{1}{u}_j dx$$

$$K_{2i,\,2j} = \overset{2}{\omega}{}_i^2 \, \delta_{ij} + \int_0^L k_s \overset{2}{u}_i \overset{2}{u}_j dx \; ; \qquad K_{2i,\,2j-1} = -\int_0^L k_s \overset{1}{u}_i \overset{2}{u}_j dx$$

and the load vector $\left\{ \{F_c\}, \{F_s\} \right\}^T$ as

$$F_{2j-1} = -\int_0^L \left\{ f_{11} \overset{1}{u}_j + m_{11} \overset{1}{v}_j \right\} dx \qquad F_{2n+2j-1} = -\int_0^L \left\{ f_{21} \overset{1}{u}_j + m_{21} \overset{1}{v}_j \right\} dx$$

$$F_{2n+2j} = -\int_0^L \left\{ f_{22} \overset{2}{u}_j + m_{22} \overset{2}{v}_j \right\} dx \qquad F_{2j} = -\int_0^L \left\{ f_{12} \overset{2}{u}_j + m_{12} \overset{2}{v}_j \right\} dx$$

The quantity δ_{ij} denotes Kronecker's delta, and $\overset{\nu}{\omega}$ is the cyclic frequency for beam number ν.

A 340,000 tdw tanker is used to illustrate the procedure. The dimensions of the ship are

L_{oa} = 370.43 meters (m)

L_{pp} = 353.30 m

B_{mld} = 56.40 m

D_{mld} = 28.43 m

The ship is divided into 75 stations located at transverse bulkheads or web frames. The fore and aft ends are approximated by equivalent bulkheads. The thick lines in Figure 7 denote transverse bulkheads; the thin lines denote web frames. The loading condition (46.9 percent displacement) is also shown in Figure 7. The mass and stiffness distributions are shown in Figure 8.

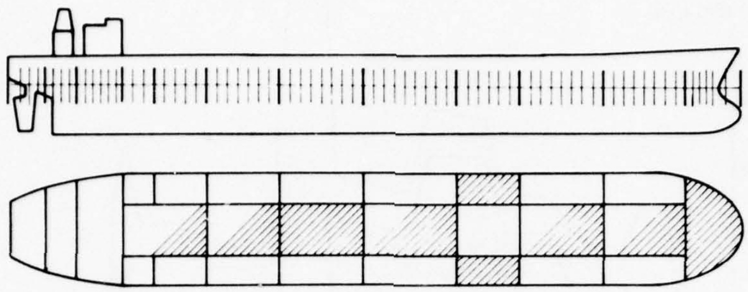

Figure 7. Positions of transverse bulkheads and web frames. Displacement ballast of 46.9% for a 340,000 tdw tanker

In all calculations the added mass is reduced according to Prohaska's expression [105] for the reduced depth of 500 m. Townsin's reduction factor [128] for the n^{th} mode -- equation (9) -- is used.

The results for free vibrations are shown in *Figure 9*. The angular rotation of the short lines illustrates the bending deflection. In the lowest modes the ship vibration approximates a Bernoulli-Euler beam. In the higher modes, shear deflection predominates, as illustrated by the approximately parallel short lines in Figure 9. Note that transverse deflection is already significant in the five-node mode.

The double-beam model is compared in Figure 10 with results obtained by modeling the hull as a single Timoshenko beam, a Bernoulli-Euler beam, a shear beam, and a Timoshenko beam with uniform mass and stiffness distributions. Successive approximation was used to determine all natural frequencies and mode shapes. The mass distribution for the Timoshenko beam is an average value that includes added mass; the stiffness is the value amidships. The virtual added mass has been reduced throughout according to Townsin's expression for the two-node mode.

The single beam model shows good agreement with the double beam theory up to five nodes. The discrepancy would have been more significant if more of the deadweight had been placed in the wing tanks as for the full load case. The Bernoulli-Euler *beam does not* adequately describe hull vibrations except for the lowest mode. The shear beam model gives frequencies that are too high for all modes. Surprisingly, the uniform Timoshenko beam, for which an analytical solution exists, is a good approximation at every frequency for this particular ship and loading condition.

In forced vibrations, the excitation forces are taken as a harmonic vertical unit force in the aft end.

The damping values in the calculations are chosen as

$$\alpha_1 = \alpha_2 = 0.630 \cdot 10^5 \text{ kg m}^{-1} \text{ sec}^{-1}$$

$$\alpha_C = 0.315 \cdot 10^5 \text{ kg m}^{-1} \text{ sec}^{-1}$$

$$\beta_1 = \beta_2 = 0.126 \cdot 10^7 \text{ kg sec}^{-1}$$

for the entire frequency range.

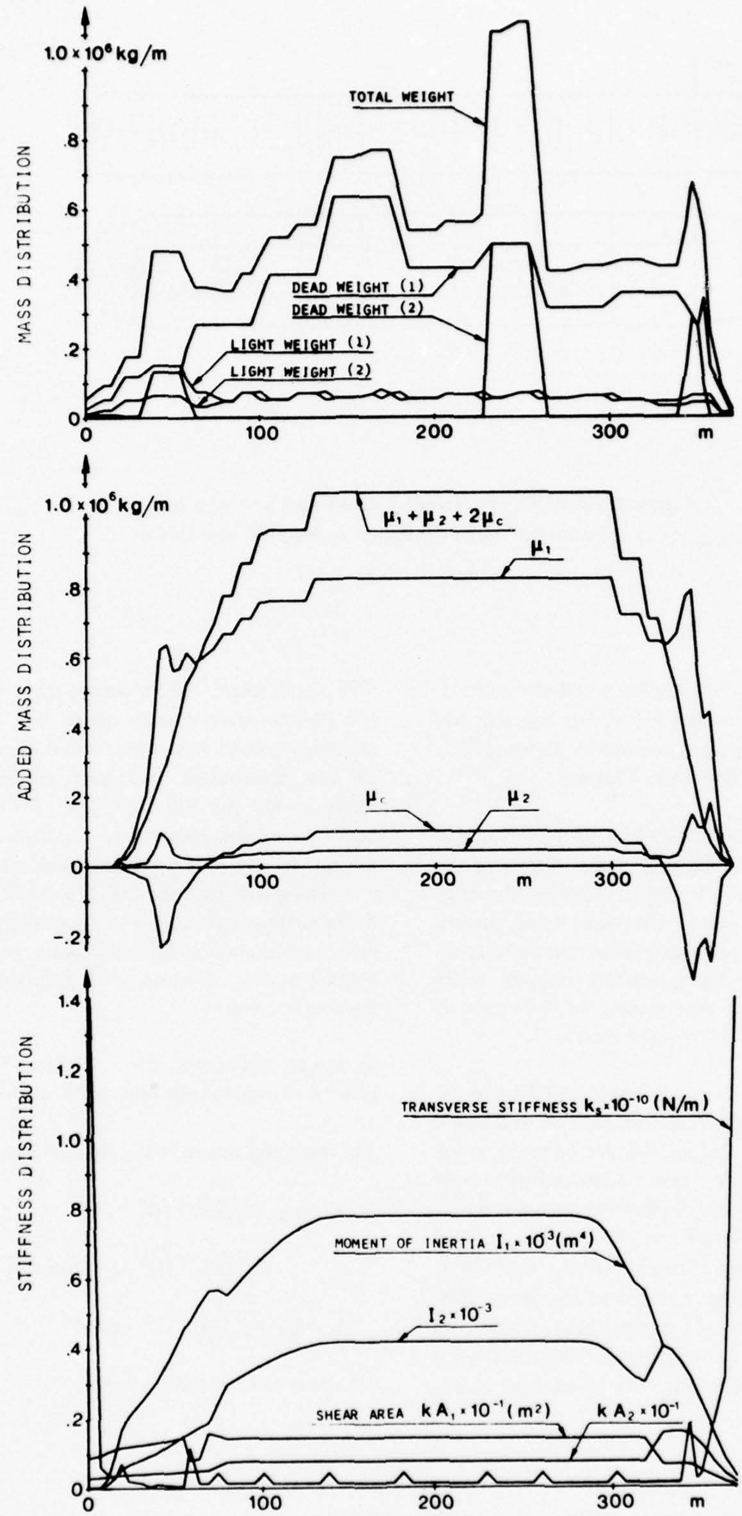

Figure 8. Mass and stiffness distributions for a 340,000 tdw tanker in the 46.9% displacement ballast condition.

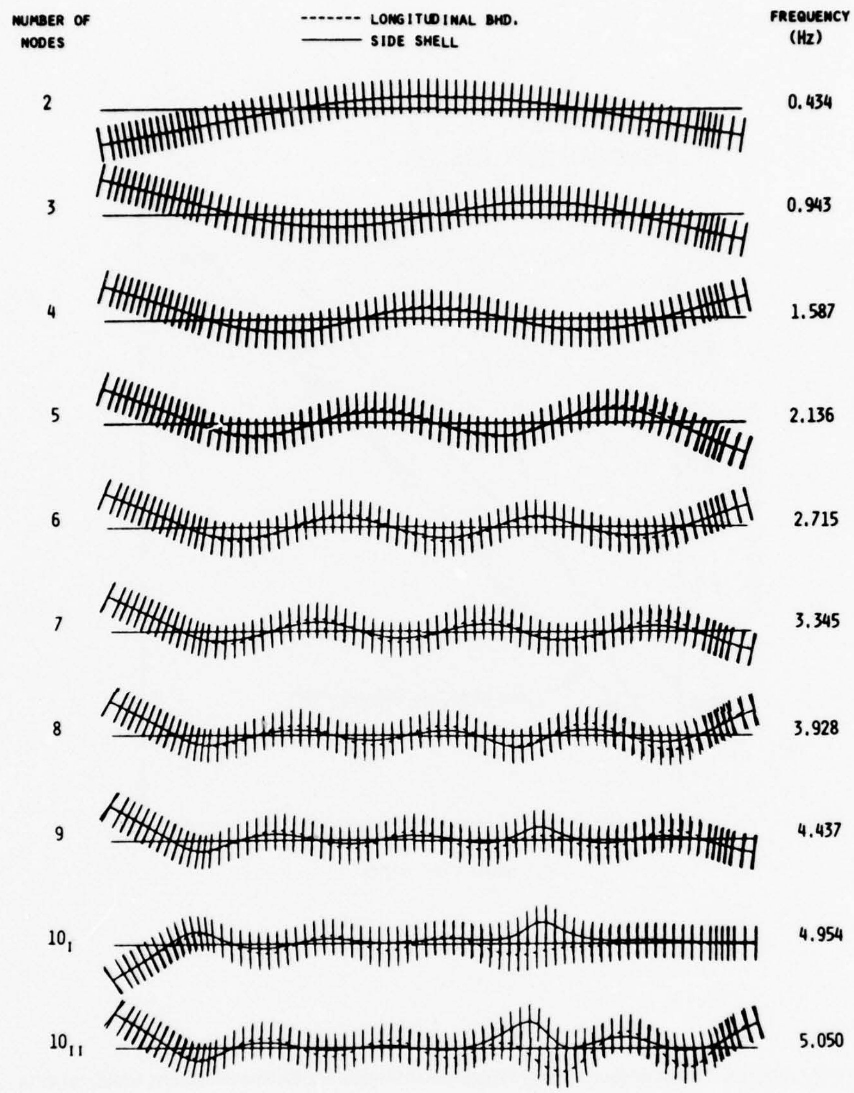

Figure 9. Natural Frequencies and Modes for a 340,000 tdw Tanker

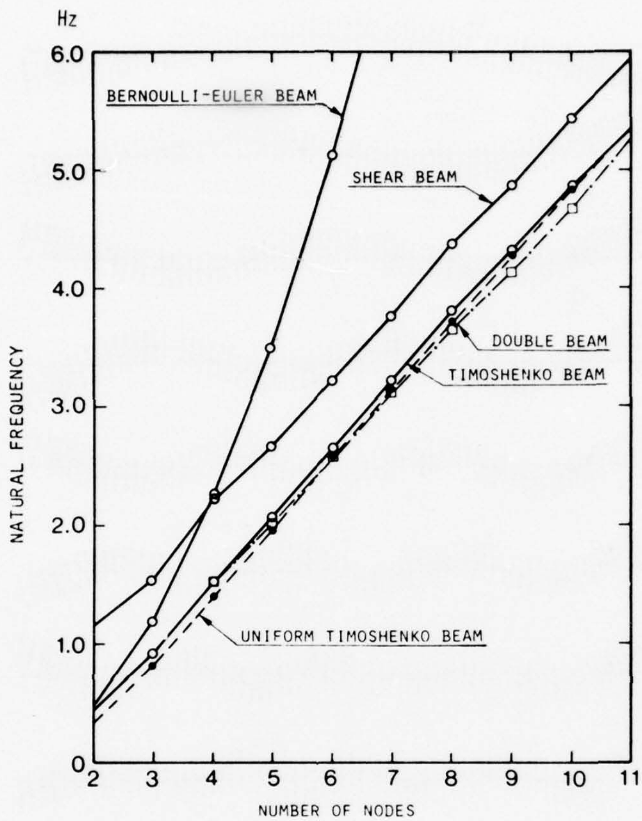

Figure 10. Natural Frequencies Versus Number of Nodes for Different Beam Idealizations of a 340,000 tdw Tanker

The vertical response of the aft end due to an oscillating unit force is shown in Figure 11.

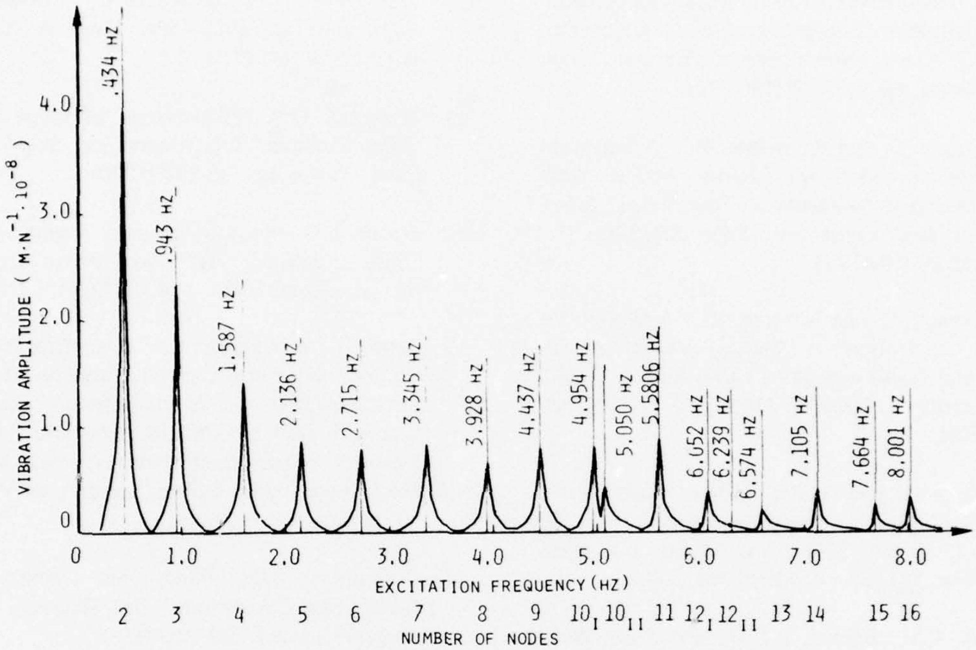

Figure 11. Vertical Response of the Aft End due to a Vertical Harmonic Oscillating Unit Force

CONCLUSIONS

The lowest natural frequencies of a ship's hull can be accurately determined by modeling the hull as a Timoshenko beam and idealizing the surrounding water as two-dimensional added masses, corrected for three-dimensional effects. Therefore, further research concerning the calculation of the lowest natural frequencies would seem to be unnecessary.

Although much information can be obtained with simple models, such as the double beam model used for the tanker, the finite element method generally must be used to determine higher natural frequencies. The limits to the accuracy of the free vibration calculations are due to the facts that the number of unknowns must be reduced to a practical number and that the effective stiffness and mass distributions must be evaluated.

Forced hull vibration analyses that provide reliable results are not possible at present. However, such analyses do provide information about the influence of design changes on vibratory behavior. The accuracy of the forced response calculations could be improved by research aimed at determining damping and the influence of cavitation on the exciting forces.

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REFERENCES

1. Aertssen, G. and deLembre, R., "Calculation and Measurement of the Vertical and Horizontal Vibration Frequency of a Large Ore Carrier," Trans. North East Coast Inst. Engr. Shipbldg., 86, pp 9-12 (1967-70).

2. Aertssen, G. and deLembre, R., "A Survey of Vibration Damping Factors Found from Slamming Experiments on Four Ships," Trans. North East Coast Inst. Engr. Shipbldg., 87, pp 83-86 (1970-71).

3. Anderson, G. and Norrand, K., "A Method for the Calculation of Vertical Vibration with Several Nodes and Some Other Aspects of Ship Vibration," Trans. RINA, 111, pp 367-383 (1969).

4. Bell, A.O. and Taylor, K.V., "Wave-Exctied Hull Vibration, Measurements on a 47,000 d.w.t. Tanker," *Shipping World and Shipbuilder*, 161, pp 412-419 (1968).

5. Bett, C.V., Bishop, R.E.D., and Price, W.G., "A Survey of Internal Hull Damping," Trans. RINA, preprint (w2) (1976).

6. Bishop, R.E.D. and Taylor, R.E.,"On Wave-Induced Stress in a Ship Executing Symmetric Motions," Phil. Trans. Roy. Soc. Lond., A275, pp 1-32 (1973).

7. Bourceau, G. and Volcy, C.G., "Forced Vibration Resonators and Forced Vibration of the Hull," Intl. Shipbldg. Prog., 18, pp 243-271 pp 275--294 (1971).

8. Breslin, J.P., "Theoretical and Experimental Techniques for Practical Estimation of Propeller-Induced Vibratory Forces," Trans. Soc. Naval Architects Marine Engr., 78, pp 23-40 (1970).

9. Breslin, J.P., "Exciting Force Operators for Ship Propellers," AIAA J. Aeronuat., 5 (3), pp 85-90 (1971).

10. Breslin, J.P., "Techniques for Estimating Vibratory Forces Generated by Propellers," Tech. and Res. Bull., Soc. Naval Architects Marine Engr. (Jan 1975).

11. Brönlund, O.E., "Eigenvalues of Large Symmetric Matrices," Proc. Fourth Intl. Ship Struc. Cong., Tokyo, pp 283-287 (1970).

12. Burrill, L.C., Robson, W., and Towsin, R.L., "Ship Vibration: Entrained Water Experiments," Trans. RINA, 104, pp 415-435 (1962).

13. Catley, D. and Norris, C., "Theoretical Prediction of the Vertical Dynamic Response of Ship Structures Using Finite Elements and Correlation with Ship Mobility Measurements," Proc. Eleventh Symp. Naval Hydrodynamics, Dept. Mech. Engr., Univ. College London, pp VI.23-VI.38 (Mar-Apr 1976).

14. Chowdhury, P.C., "Fluid Finite Elements for Added-Mass Calculations," Intl. Shipbldg. Prog. 19 (217), pp 302-309 (1972).

15. Collatz, L., "Eigenwertaufgaben mit technischen Anwendungen," Akademische Verlagsgesellschaft, Geest and Portig, 2. Auflage, Leipzig (1963).

16. Cowper, G.R., *"The Shear Coefficient in* Timoshenko's Beam Theory," J. Appl Mech., Trans. ASME, 33, p 335 (1966).

17. Csupor, D.A., "Zur Theorie un Berechnung der freien ungedämpften Schwingungen des Schiffskörpers," Diss. TH Hannover (1956).

18. Dawson, B. and Davies, M., "An Addition to Myklestad's Method Giving Convergence to a Natural Frequency," J. Ship Res., 19 (2), pp 130-132 (1975).

19. Frank, W., "Oscillating of Cylinders in or below the Free Surface of Deep Fluids," NSRDC, Washington, D.C., Rep. No. 2375 (1967).

20. Fried, I., "Condensation of Finite Element Eigenproblems," AIAA J., Tech. Note, 10 (11), pp 1529-1530 (1972).

21. Frivold, H., "Solid Boundary Factors for the Afterbody of an LNG Carrier," Norwegian Maritime Res., 4 (1), pp 16-20 (1976).

22. van Gent, W., "Unsteady Lifting-Surface Theory for Ship Screws: Derivation and Numerical Treatment of Integral Equation," J. Ship Res., 19 (4), pp 243-253 (1975).

23. Goodman, R.A., "Wave-Excited Main Hull Vibration in Large Tankers and Bulk Carriers," Trans. RINA, 113, pp 167-184 (1971).

24. Grim, A., "Hydrodynamic Masses," Schiffstechnik, 5 (29) (1958).

25. van Gunsteren, F.F., "Springing, Wave-Induced Ship Vibration," Intl. Shipbldg. Prog., 17 (195), pp 333-347.

26. Gupta, K.K., "Recent Advances in Numerical Analysis of Structural Eigenvalue Problems," in Theory and Practice in Finite Element Structural Analysis, Proc. 1973 Tokyo Seminar Finite Element Anal., pp 249-271.

27. Guyan, R.J., "Reduction of Stiffness and Mass Matrices," AIAA J., 3 (2), p [illegible]0 (1968).

28. Hansen, H.R. and Skaar, K.T., "Hull and Superstructure Vibrations, Design Calculation by Finite Elements," Proc. Symp. High Powered Propulsion Large Ships, Netherlands Ship Model Basin, Wageningen (1974).

29. Hart, H.H.'t, "Hull Vibrations of the Cargo-Liner Koudekerk," Intl. Shipbldg. Prog., 18 (206), pp 373-383 (1971).

30. Havelock, T.H., "Ship Vibrations: the Virtual Inertia of a Spheroid in Shallow Water," Quart. Trans. INA, 95 (1953).

31. Hirowatari, T., "Magnification Factors in the Higher Modes of Ship Vibration," JSNA-Japan, 113, pp 156-168 (1963).

32. Huse, E., "Hull Vibration and the Measurements of Propeller-Induced Pressure Fluctuations," Intl. Shipbldg. Prog., 17 (187), pp 87-95 (1970).

33. Huse, E., "Pressure Fluctuations on the Hull-Induced by Cavitating Propellers," Norwegian Ship Model Expt. Tank, Publ. No. 111 (Mar 1972).

34. Hylarides, S., "Lowest Natural Frequencies of Structures with Rigid-Body Degrees of Freedom," J. Ship Res., 12 (2), pp 131-136 (1968).

35. Hylarides, S., "Finite Element Technique in Ship Vibration Analysis," Intl. Shipbldg. Prog., 15 (169), pp 328-338 (1968).

36. Hylarides, S., "Recent Developments in Hull and Shaft Vibration Analysis," Intl. Shipbldg. Prog., 17 (190), pp 185-190 (1970).

37. Hylarides, S., "Hull Resonance: An Explanation of Excessive Vibrations," Intl. Shipbldg. Prog., 21 (236), pp 89-99 (1974).

38. Hylarides, S., "Damping in Propeller-Generated Ship Vibrations," Netherlands Ship Model Basin, No. 468 (1974).

39. Proc. First International Ship Structures Congress, Glasgow (1961).

40. Proc. Second International Ship Structures Congress, Delft, The Netherlands (1964).

41. Proc. Third International Ship Structures Congress, Oslo, Norway (1967).

42. Proc. Fourth International Ship Structures Congress, Tokyo, Japan (1970).

43. Proc. Fifth International Ship Structures Congress, Hamburg, West Germany (1973).

44. Johnson, A.J., "Vibration Tests of All-Welded and All-Riveted 10,000 Ton Dry Cargo Ship," Trans. North East Coast Inst. Engr., 67, pp 205-276 (1950-51).

45. Johnson, A.J., Ayling, P.W., and Couchman, A.J., "On the Vibration Amplitudes of Ships' Hulls," Trans. Instn. Engr. Shipbldg. Scotland, 105, pp 301-387 (1962).

46. Joosen, W.P.A. and Spangenberg, J.A., "On the Longitudinal Reduction Factor for the Added Mass of Vibrating Ships with Rectangular Cross-Section," Netherlands Research Centre, TNO, No. 40S (1961).

47. Kagawa, K. and Ohtaka, K., "Higher Mode Vertical Vibration of Giant Tanker," 2nd Rep., JSNA-Japan, 128, pp 295-309 (1970).

48. Kagawa, K. and Miyamoto, M., "Hull Vibration of Container Ship," Mitsubishi Tech. Bull. No. 81 (1972).

49. Kawakami, M. and Kiso, T., "On the Wave-Induced Ship Hull Vibration," JSNA-West Japan No. 51 (Mar 1976).

50. Kline, R.G and Daidola, J.C., "Ship Vibration Prediction Methods and Evaluation of Influence of Hull-Stiffness Variation on Vibratory Response," Ship Struc. Committee, U.S. Coast Guard No. 249 (1975).

51. Kline, R.G. and Daidola, J.C., "Bibliography for Ship Vibration Prediction Methods and Evaluation of Influence of Hull-Stiffness Variation on Vibratory Response," Ship Struc. Committee, U.S. Coast Guard No. 250 (1975).

52. Kruppa, C., "Beitrag zum Problem der hydrodynamischen Trägheitsgrössen bei elastichen Schiffsschwingungen," Schiffstechnik, 9 (45), pp 38-60 (1962).

53. Kuiper, G., "Some Remarks on Lifting Surface Theory," Intl. Shipbldg. Prog., 18 (199), pp 131-148 (1971).

54. Kumai, T., "Shearing Vibrations of Ships," Eur. Shipbldg., 5 (2), pp 32-37 (1956).

55. Kumai, T., "The Effect of Loading Conditions on the Natural Frequency of Hull Vibration," Rep. R.I.A.M., Kyushu Univ. Japan, 5 (17), pp 9-20 (1957).

56. Kumai, T., "Damping Factors in the Higher Modes of Ship Vibration," Eur. Shipbldg., 7 (1), pp 29-34 (1958).

57. Kumai, T., "Added Mass Moment of Inertia Induced by Torsional Vibration of Ships," Rep. R.I.A.M., Kyushu Univ. Japan, 7 (28), pp 233-244 (1959).

58. Kumai, T., "Some Correction Factors for the Virtual Inertia Coefficient for the Horizontal Vibrations of a Ship," Rep. R.I.A.M., Kyushu Univ. Japan, 9 (33), pp 17-25 (1961).

59. Kumai, T. et al, "Measurement of Propeller Forces Exciting Hull Vibration by Use of Self-Propelled Model," Rep. R.I.A.M., Kyushu Univ. Japan, 9 (33), pp 1-15 (1961).

60. Kumai, T., "Some Aspect of the Propeller Bearing Forces Exciting Hull Vibration of a Single Screw Ship," Rep. R.I.A.M., Kyushu Univ. Japan, 9 (33), pp 27-34 (1961).

61. Kumai, T., "The Effect of Distribution of Load upon the Virtual Inertia Coefficient in the Vertical Vibration of a Ship," Rep. R.I.A.M., Kysuhu Univ. Japan, 10 (37) (1962).

62. Kumai, T., "On the Three-Dimensional Correction Factor for the Virtual Inertia Coefficient in the Vertical Vibration of Ships," JSNA-Japan, 112 (Dec 1962).

63. Kumai, T. and Ochi, Y., "On the Vibration of Ships in Wave," Rep. R.I.A.M., Kyushu Univ. Japan, 11 (40), pp 13-19 (1963).

64. Kumai, T., "On the Apparent Mass of Cargo Oil in Vibration of a Tanker," Rep. R.I.A.M., Kyushu Univ. Japan, 13 (46), pp 69-78 (1965).

65. Kumai, T., "Effect of Shear Deflection and Rotatory Inertia on the Damping of the Flexural Vibration of a Ship Hull," Rep. R.I.A.M., Kyushu Univ. Japan, 13 (46), pp 61-68 (1965).

66. Kumai, T. and Sakurada, Y., "On the Measurements of Propeller Surface Force of the Self-Propelled Model of a Tanker," Rep. R.I.A.M., Kyushu Univ. Japan, 13 (46), pp 79-95 (1965).

67. Kumai, T., "A Method for Evaluating the Three-Dimensional Reduction Factor of the Virtual Mass in the Vertical Vibration of Ships," Japan Shipbldg. Marine Engr., 1 (3), pp 15-21 (1966).

68. Kumai, T., "Vibration of a Mammoth Tanker with Special Consideration to Athwartship Flexibility," Eur. Shipbldg., 16 (3), pp 50-53 (1967).

69. Kumai, T., "On the Estimation of Natural Frequencies of Vertical Vibration of Ships," Rep. R.I.A.M., Kyushu Univ. Japan, 16 (54), pp 239-250 (1963).

70. Kumai, T. and Tasai, F., "On the Wave Exciting Force and Response of Whipping of Ships," Eur. Shipbldg., 19 (4), pp 42-47 (1970).

71. Kumai, T., "Wave-Induced Force Exciting Hull Vibration and Its Response," JSNA-West Japan, No. 44 (Aug 1972).

72. Kumai, T., "On the Three-Dimensional Entrained Water in Vibration of Lewis' Section Cylinder with Finite Length," JSNA-West Japan, No. 50 (Aug 1975).

73. Lamb, H., Hydrodynamics, Cambridge Univ. Press (1895).

74. Landweber, L. and Macagno, M., "Added Mass of Two-Dimensional Forms Oscillating in a Free Surface," J. Ship Res., 1 (3), pp 20-30 (1957).

75. Landweber, L. and Macagno, M., "Added Mass of a Three Parameter Family of Two-Dimensional Forms Oscillating in a Free Surface," J. Ship Res., 2 (4) (1959).

76. Landweber, L. and Macagno, M., "Added Mass of a Rigid Prolate Spheroid Oscillating Horizontally in a Free Surface," J. Ship Res., 3 (4), pp 30-36 (1960).

77. Landweber, L. and Macagno, M., "Added Mass of Two-Dimensional Forms by Conformal Mapping," J. Ship Res., 11 (2), pp 109-116 (1967).

78. Landweber, L., "Vibration of a Flexible Cylinder in a Fluid," J. Ship Res., 11 (3), pp 143-150 (1967).

79. Landweber, L., "Natural Frequencies of a Body of Revolution Vibrating Transversely in a Fluid," J. Ship Res., 15 (2), pp 97-114 (1971).

80. Lazan, B.J., Damping of Materials and Members in Structural Mechanics, Pergamon Press, London (1968).

81. Leibowitz, R.C. and Kennard, E.H., "Theory of Freely Vibrating Non-Uniform Beams, Including Methods of Solution and Application to Ships," David Taylor Model Basin Rep. 1317 (1961).

82. Lewis, F.M., "The Inertia of the Water Surrounding a Vibrating Ship," Trans., Soc. Naval Architects Marine Engr., 37, pp 1-20 (1929).

83. Lewis, F.M., "Propeller-Vibration Forces," Trans., Soc. Naval Architects Marine Engr., 71, pp 293-318 (1963).

84. Lewis, F.M., "Propeller Vibration Forces in Single-Screw Ships," Trans., Soc. Naval Architects Marine Engr., 77, pp 318-334 (1969).

85. Lin, Y.K., Probalistic Theory of Structural Dynamics, McGraw-Hill (1967).

86. Little, R.S. and Lewis, E.V., "A Study of Wave-Induced Bending Moments," Shipping World and Shipbuilder, 165 (3867), pp 357-360.

87. Madsen, N., "Vertikale Skrogsvingninger i Store Tankskibe," Dept. Ocean Engr., Tech. Univ. Denmark (1975).

88. Maeda, Y., "On the Coupled Vibration of the Longitudinal Vibration, Vertical Vibration and the Vibration of Shaft System," 2nd Rep., JSNA-West Japan, No. 44 (Aug 1972).

89. Mathewson, A.W., "Calculation of the Normal Vertical Flexural Modes of Hull Vibration by Digital Process," David Taylor Model Basin Rep. 706 (1950).

90. McGoldrick, R.T. and Russo, V.L., "Hull Vibration Investigation on SS Gopher Mariner," Trans., Soc. Naval Architects Marine Engr., 63, pp 436-475 (1955).

91. McGoldrick, R.T., "Ship Vibration," David Taylor Model Basin Rep. 1451 (1960).

92. Meirovitch, L., Analytical Methods in Vibrations, MacMillan, London (1967).

93. Misra, Prayag Narayan, "Transverse Vibrations of a Ship Hull in Ideal Fluid, Determined through Variational Methods," J. Ship Res., 18 (3), pp 185-202 (1974).

94. Myklestad, N.O., "A New Method for Calculating Natural Modes of Uncoupled Bending Vibrations of Airplane Wings and Other Types of Beams," J. Aeron. Sci., 11, pp 153-162 (1944).

95. Nering, K. et al, "Theroetische und experimentelle Untersuchungen zur Beeinflussung der Resonanzschwingungen des Schiffskörpers ausgeführt an einer Serie von Kühl- and Transportschiffen," Schiffbauforschung, 13 (1/2), pp 1-13 (1974).

96. Ohtaka, K., Kumai, T., Ushijima, M., and Ohji, M., "On the Horizontal and Torsional Vibration of Ships," JSNA-Japan, 121 (June 1967).

97. Ohtaka, K., Kagawa, K., and Yamamoto, T., "Higher Mode Vertical Vibration of a Giant Tanker," JSNA-Japan, 125 (1969).

98. Ohtaka, K., "Vertical Vibration of Ships Coupled with Bottom Vibration," Mitsubishi Tech. Bull. No. 83 (1973).

99. Oossanen, P. van and Kooy, J. van der, "Vibratory Hull Forces Induced by Cavitating Propellers," Trans. RINA, 115, pp 111-144 (1973).

100. Oosterveld, M.V.C., Verdonk, C., Kooy, J. van der, and Oossanen, P. van der, "Some Propeller Cavitation and Excitation Considerations for Large Tankers," West European Conf. Mar. Tech. Proc., Delft (May 1974).

101. Palm, L., "Ermittlung der Schubsteifigkeit zur Berechnung höherer Eigenfrequenzen und Eigenformen von vertikalen Schiffskörperschwingungen," Schiffbauforschung, 14 (5/6), pp 153-162 (1975).

102. Pohl, K.H., "Die durch eine Schiffschraube auf benachbarten Platten erzeugten periodischen hydrodynamischen Drücke," Schifftechnik, 7 (35), pp 5-18 (1960).

103. Porter, W.R., "Pressure Distributions, Added-Mass and Damping Coefficients for Cylinders Oscillating in a Free Surface," Inst. Engr. Res., Univ. Cal. (1960).

104. Postl, R., "Elastische Schwingungen in der Schiffstechnik," Z. Agnew. Math. Mech., 52, pp T281-T287 (1972).

105. Prohaska, C.W., "Vibrations Verticales du Navire," Bull. de l'Association Technique Maritime et Aéronautique (1947).

106. Reed, F.E., "The Design of Ships to Avoid Propeller-Excited Vibrations," Trans., Soc. Naval Architects Marine Engr., 79, pp 244-280 (1971).

107. Restad, K., Volcy, G.C., Garnier, H., and Masson, J.C., "Investigations on Free and Forced Vibrations of an LNG Tanker with Overlapping Propeller Arrangement," Trans., Soc. Naval Architects Marine Engr., 81, pp 307-347 (1973).

108. Robinson, D.C., "Damping Characteristics of Ships in Vertical Flexure and Considerations in Hull Damping Investigations," David Taylor Model Basin, No. 1876 (Dec 1964).

109. Ruiz-Fornells, R. et al, "Hull Vibrations," Astilleros Espanoles, S.A. Symp. Paper, BSRA Trans. No. 3888 (1976).

110. Schade, H.A., "Effective Breadth of Stiffened Plating," Trans., Soc. Naval Architects Marine Engr., 59, pp 403-430 (1951).

111. Schade, H.A., "Effective Breadth Concept in Ship Structures," Trans., Soc. Naval Architects Marine Engr., 60, pp 410-430 (1953).

112. Schadlofsky, E., "The Calculation and Measurement of Elastic Natural Frequencies of Ship Hulls," Schiffbautechnische Gesellschaft, 13 (1932).

113. Schlick, O., "On the Vibration of Steam Vessels," Trans. INA (1884).

114. Schmitz, K-P, "Zum Problem der erzwungenen gekoppelten horizontal - torsionsschwingungen des Schiffskörpers," Schiffbauforschung, 13 (1/2), pp 14-19 (1974).

115. Sellers, M.L. and Kline, R.G., "Some Aspects of Ship Stiffness," Trans., Soc. Naval Architects Marine Engr., 75, pp 268-288 (1967).

116. Senjanović, I. and Skaar, K.T., "Problems of Coupling between Ship Hull and Substructure Vibration," HANSA, 112 (20), pp 1574-1578 (1975).

117. Senjanović, I. and Skaar, K.T., "Problems of Ship Vibration Present Solutions and Further Investigations," Trans., Soc. Naval Architects Marine Engr., Sp. Mtg. (June 1976).

118. Sezawa, K. and Watanabe, W., "Damping Forces in Vibration of a Ship," JSNA-Japan, 59 (1936).

119. Shioiri, J. and Tsakonas, S., "Three-Dimensional Approach to the Gust Problem for a Screw-Propeller," J. Ship Res., 7 (4), pp 29-53 (1964).

120. Smith, C.S., "Buckling and Vibration of a Ships Vee- Bottom Structure," Trans. RINA, 116, pp 261-274 (1974).

121. Sparenberg, J.A., "Application of Lifting Surface Theory to Ship Screws," Koninkl. Ned. Akad. Wetenschap, Proc. Amsterdam, 62, Ser. B (1959).

122. Suetsugu, I. and Fujii, K., "The Effect of the Bottom Vibration on the Hull Natural Frequencies," Intl. Shipbldg. Prog., 10 (109), pp 351-364 (1963).

123. Tasai, F., "Formula for Calculating Hydrodynamic Force of a Cylinder Heaving on a Free Surface (n-Parameter Family)," Note Rep. RIAM, Kyushu Univ. Japan, 8 (31), pp 71-74 (1960).

124. Taylor, J.L., "Some Hydrodynamical Inertia Coefficients," Phil. Mag., 9 (1930).

125. Taylor, J.L., "Vibration of Ships," Trans. INA (1930).

126. Todd, F.H., "Some Measurements of Ship Vibration," Trans. North East Coast Instn. Engr. Shipbldg., 48, pp 65-88 (1931 32).

127. Todd, F.H., Ship Hull Vibration, Edw. Arnold, London (1961).

128. Townsin, R.L., "Virtual Mass Reduction Factors, J'Values for Ship Vibration Calculations Derived from Tests with Beams Including Ellipsoids and Ship Models," Trans. RINA, 111, pp 385-397 (1969).

129. Tsakonas, S., Breslin, J.P., and Miller, M., "Correlation and Application of an Unsteady Flow Theory for Propeller Forces," Trans., Soc. Naval Architects Marine Engr., 75, pp 158-180 (1967).

130. Tsakonas, S., Jacobs, W.R., and Rank, P.H., "Unsteady Propeller Lifting-Surface Theory with Finite Number of Chordwise Modes," J. Ship Res., 12 (1), pp 14-45 (1968).

131. Tsakonas, S. and Jacobs, W.R., "Propeller Loading Distributions," J. Ship Res., 13 (4), pp 237-257 (1969).

132. Tsakonas, S. et al, "Documentation of a Computer Program for the Pressure Distribution, Forces and Moments on Ship Propellers in Hull Waves," Stevens Inst. Tech., Rep. SIT-DL-76-1863 (1976).

133. Verbrugh, P.J., "Unsteady Lifting Surface Theory for Ship Screws," Netherlands Ship Model Basin Rep. 68-036-AH, 62 (5) (1968).

134. Vorus, W.S., "A Method for Analyzing the Propeller-Induced Vibratory Forces Acting on the Surface of a Ship Stern," Trans., Soc. Naval Architects Marine Engr., 82, pp 186-198 (1974).

135. Ward, G. and Willshare, G.T., "Propeller-Excited Vibration with Particular Reference to Full-Scale Measurements," RINA Sp. Mtg., Paper No. 4 (1975).

136. Wereldsma, R., "Tendencies of Marine Propeller Shaft Excitations," Intl. Shipbldg. Prog., 19 (218), pp 328-332 (1972).

137. Wereldsma, R. and Moeyes, G., "Wave and Structural Load Experiments for Elastic Ships," Eleventh Symposium Naval Hydrodynamics, Dept. Mech. Engr., Univ. College London, pp VI.3-VI.15 (Mar-Apr 1976).

138. Yamakoshi, M. and Ohnuma, S., "On the Coupling of Hull Vibration and Bottom Vibration of Ships," JSNA-Japan, 118 (Dec 1965).

INA: Institution of Naval Architects, London

RINA: Royal Institution of Naval Architects

JSNA: Journal of the Society of Naval Architects, Tokyo

RIAM: Research Institute for Applied Mechanics

BSRA: British Ship Research Associates

UNDERWATER FLUID-STRUCTURE INTERACTION
PART IV: HYDRODYNAMICALLY APPLIED FORCES (MOVING MEDIUM)

L.H. Chen* and M. Pierucci**

Abstract - Fluid-structure interaction encompasses a broad spectrum of technical areas of interest in engineering application. This discussion is limited to "underwater" applications and includes the following topics: sound radiation and scattering, structural vibration and shock response, flow-induced noise, hydrodynamic divergence and flutter, boundary layer stability, and propeller-induced forces. The common thread linking these technologies, namely, the interaction phenomenon, is stressed. An attempt has been made to clarify some of the terminology within these diverse technical areas.

A flowing fluid next to a structure introduces another degree of difficulty to the problem of fluid-structure interaction because the flow field plays an active role in both structural and fluid vibrations. In the zero mean velocity cases already considered, the fluid altered only the vibrational characteristics of the structure. When the fluid attains a mean velocity, it becomes an active partner in the interaction by imposing a fluid force on the structure that is related to the mean flow velocity. Depending upon the fluid velocity and the phenomena being explored, the fluid either has a purely active role, a purely passive role, or is a combination of both.

Four fluid-structure interaction problems are considered:

- TBL (turbulent boundary layer) flow-induced noise -- fluid has passive role
- generalized dynamic divergence of compliant surfaces -- fluid has active role
- stability of boundary layers on compliant surfaces -- fluid has active role
- propeller-induced forces -- fluid has active role

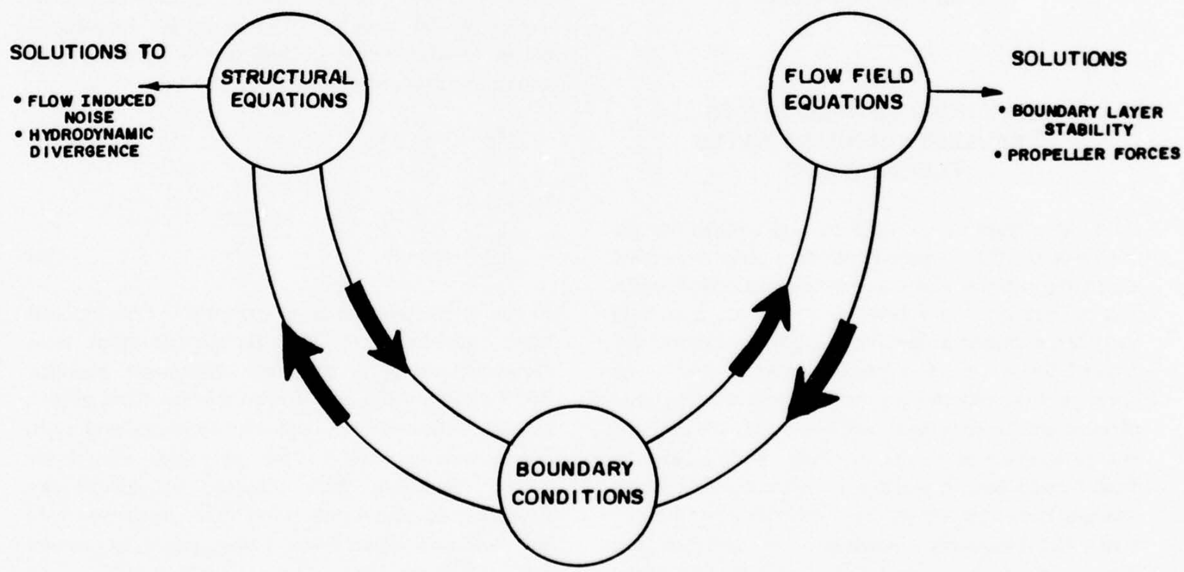

Figure 1. Structure Flow Field Interaction

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In an exact representation of these phenomena, each interaction is controlled by the same basic equations. Figure 1 is a generalized flow chart of the interaction. Any interaction problem is difficult to solve exactly; approximate solutions are possible for the phenomena listed above, however. Figure 2 shows interaction problems and the relationship between any two.

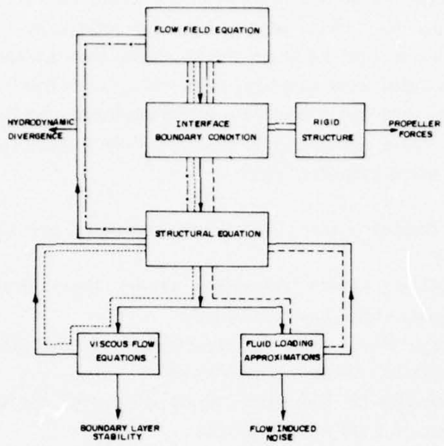

Figure 2. State-of-the-Art of Structure Flow Field Interaction

FLOW-INDUCED NOISE DUE TO TURBULENT BOUNDARY LAYER FLUCTUATIONS

As a flow field moves next to a structure, the viscosity of the fluid causes a boundary layer to develop about the surface. For the examples described in this section the boundary layer is turbulent. The fluid turbulence causes a pressure fluctuation on the surface of the structure. If the structure is elastic, the pressure fluctuations, subject to fluid loading conditions, induce structural vibrations, and the acoustic energy radiates from the structure. In this case the fluid plays a passive active role because fluid loading changes only the vibrational response of the structure. No interaction between the structure and pressure fluctuations caused by the turbulent boundary layer is accounted for.

The equation governing the turbulent boundary layer-induced noise is

$$D_S[\bar{w}] = F(\bar{U}) + P(\bar{w}^*) \tag{32}$$

The function $F(\bar{U})$ represents the turbulent boundary layer pressure fluctuations and in general cannot be obtained deterministically; the solution to equation (32) is thus written in a statistical form. Because the algebraic complexity of the problem is thus increased and the underlying assumption and technique used in the solution are not clarified, it is assumed that the general approach to the solution to equation (32) is the same for deterministic and statistical forcing functions. A detailed description of the analysis required for this assumption for both an infinite and a finite plate has been published [50].

The fluid-structure interaction force $P(\bar{w}^*)$-- that is, the passive fluid force -- is obtained from the fluid equation and the boundary condition in which fluid velocity is equal to structural velocity:

$$D_f[\bar{u}] = F(\bar{U}) + P(\bar{w}^*) \tag{33}$$

$$\bar{w}^* = \bar{u} \tag{34}$$

For structure and flow conditions such that the flow velocity is less than the velocity of propagation of the structural vibrations -- that is, for frequencies below hydrodynamic coincidence -- equation (33) and boundary conditions reduce to

$$\nabla^2 \phi = \frac{1}{c^2} \phi^{**} \tag{35}$$

subject to

$$\frac{\partial \phi}{\partial n} = w^* \tag{36}$$

In the initial work done in the area of flow-induced noise, radiated noise and surface vibration were calculated using a complete decoupled analysis. The function $F(\bar{U})$ was known a priori from experimental measurements, and the fluid loading term $P(\bar{w}^*)$ was assumed to be negligible. Values for surface vibrations were obtained by solving the structural equations, equation (32), independent of any fluid interaction force. The structural vibrational modes were then imposed on the wave equation, and the resulting radiated noise was evaluated. The no fluid-loading condition is a good approximation for in-air structures and for high frequency in-water

conditions. The structural and fluid equations can thus be solved independently and the two solutions coupled by the interface conditions. Structural techniques used to solve the structural equations, include the Fourier transform for infinite structures, Galerkin's method for finite membranes or plates, and the finite element method for more complex structures. After values for structural vibrations are obtained, the wave equation is solved either by Fourier transform or by Green's function technique with a known source strength distribution. The two solutions are coupled by the interface condition.

The fluid-loading conditions of in-water cases introduce a term for mass loading and one for radiation loading. The mass loading term is significant at low frequencies and has been used in surface vibration studies by assuming that the added mass is constant. This assumption decouples the fluid-structure interaction problem. The radiation loading term, which is critical for the radiated far field problem, has been assumed to be a modified form of the ρc loading [16]. Both assumptions decouple the fluid-structure interaction problem because the wave equation is replaced by the approximate mass or radiation loading condition. The structural engineer uses mass-loading approximations to solve vibration problems; the flow noise investigator uses the fluid-loading approximation to predict radiated flow-induced noise. No exact analytical solution has been shown to be valid over an entire spectrum, be it near field, far field, low frequency, or high frequency. The solution to the exact coupled problem is valid for an infinite plate only in the far field [22].

A detailed description of various coupled problems and their respective solutions has been published [37], as has a list of papers [37, 50]. It is not yet possible to determine the effect, either analytically or experimentally, of surface vibration upon fluctuations in the turbulent boundary layer pressure. This is probably a critical problem if the wavelength of the structural vibrations is of the same order of magnitude or smaller than the typical eddy dimension of the fluid.

GENERALIZED STRUCTURAL DIVERGENCE

Any disturbance at the interface between a structure and a flowing fluid may, under suitable circumstances, become unstable. The instability can be in the structure or in the fluid. The stability of the boundary layer next to the wall is of interest in fluid mechanics. The solution of such fluid problems involves coupling the viscous equation to that for a relatively simple structure.

The stability of surface disturbances is of interest in structural dynamics. In such problems, the thin plate or elastic layer is assumed to be influenced only by the potential flow-field pressure; any viscous interaction is neglected. Three surface instabilities can be analyzed: static temporal divergence, spatial divergence, and flutter or dynamic divergence.

Surface waves can diverge in either time or space. A combination of temporal and spatial effects causes flutter. Flutter is usually used to define the effect in air flow analysis; dynamic divergence is used in water flow analysis. The two phenomena are for all practical purposes the same.

The system of equations that defines the generalized surface stability is shown below.

$$D_S[\bar{w}^*] = \Delta p \tag{37}$$

$$\nabla^2\phi - \frac{1}{c^2}\left(\frac{\partial}{\partial t} + U\frac{\partial}{\partial x}\right)^2\phi = 0 \tag{38}$$

$$\frac{\partial\phi}{\partial n} = \left[\frac{\partial w}{\partial t} + U\frac{\partial w}{\partial x}\right]\Big|_{z=0} \tag{39}$$

The structural forcing function Δp is given by equation (40).

$$\Delta p = -\rho\left(\frac{\partial\phi}{\partial t} + U\frac{\partial\phi}{\partial x}\right)\Big|_{z=0} \tag{40}$$

The fluid force Δp in equation (40) increases as structural displacement w increases and vice versa. As a result of such interaction, any infinitesimal disturbance grows without bounds, creating a surface instability called divergence. The stability of the coupled system is determined instead of solving the coupled problem. The basic analytical technique has been similar in all work published to date. The form of the structural equation, equation (37), depends upon whether the model chosen to represent the structure under consideration is a membrane, a thin plate, a thick plate, or an elastic layer. The method

of solution depends upon the boundary conditions at the edges of the structure. A Fourier transform approach is used for an infinite boundary; the Galerkin method is used for a simply supported or fixed plate problem.

Regardless of the approach chosen, a compatibility equation is derived from equation (39). Depending upon the mathematical models chosen for the structure, the compatibility equation is a relatively simple transcendental equation or a more complex equation involving evaluation of integrals. Solution of the compatibility equation defines the boundary between stable and unstable conditions. The instabilities may be in either time, space, or both. If the instability is a function of either space or time, the stability condition is called static divergence.

The flutter problem has been thoroughly reviewed: in one review [18] structural solutions for panel flutter and flow-induced panel noise have been compared [18]; in the other, a list of flutter computer programs has been compiled [26]. Static divergence for a generalized elastic layer in the absence of a fluid has been analyzed [51]. Stability conditions for a membrane in the presence of an inviscid flow field have been determined [40]. Boggs' analysis has been used to incorporate the effect of the fluid force due to the flowing fluid on the stability of *surface waves* [45].

STABILITY OF A TURBULENT BOUNDARY LAYER ON A COMPLIANT SURFACE

Kramer [34] performed original experiments on flow fields over compliant surfaces in 1960; since then, others have tried to understand the reasons for his success in achieving drag reduction. Those who think that compliance increases the stability of any turbulent disturbance in a boundary layer are opposed to those who believe that the stability of the disturbances actually decreases [9, 10, 12, 25, 36, 53].

A wall next to a flowing fluid experiences three modes of instabilities: class A, class B, and Kelvin-Helmholtz. Class A instabilities are fluid waves that are stabilized by the inclusion of structural damping. Class B instabilities are surface waves that move at a phase velocity almost equal to that of the free surface wave on the structure. The Kelvin-Helmholtz (K-H) instability occurs at the interface between the fluid and structure. Small damping values aggravate the K-H instability; larger values have a stabilizing effect.

The stability of fluid disturbances is a linearized form of the Navier-Stokes equation, which can be represented by the Orr-Sommerfeld equation

$$(U - c)\left(\frac{\partial^2 \phi}{\partial x^2} - k^2\phi\right) - \frac{\partial^2 U}{\partial x^2}\phi \tag{41}$$

$$+ \frac{i}{\alpha R_e}\left(\frac{\partial^4 \phi}{\partial x^4} - 2k^2 \frac{\partial^2 \phi}{\partial x^2} + k^4\phi\right) = 0$$

For a rigid surface the boundary conditions reduce to

$$\phi(0) = \frac{\partial \phi}{\partial x}(0) = 0 \tag{42}$$

and

$$\lim_{y \to \infty} \phi(y) = \frac{\partial \phi}{\partial x}(y) = 0 \tag{43}$$

Solutions of this system of equations have been well documented, including solutions to the boundary layer stability *over rigid surfaces* [39].

For flow over a compliant surface, surface boundary conditions are [5]

$$\psi = \bar{w}\ , \tag{44}$$

$$\frac{\partial \psi}{\partial y} = -\bar{w}\frac{dU}{dy}\ , \tag{45}$$

where ψ is the streamline function. The structural displacement w is governed by

$$D_s[\bar{w}] = F(\bar{U}) + P(\bar{w}^*)\ . \tag{46}$$

The interaction between fluid waves and structural waves (represented by a membrane) has been analyzed [5, 35]. A predetermined surface vibration was imposed, and its effect upon the stability of the flow field was then determined. The variation of turbulent

Reynold stresses has been analyzed as a function of the surface wave speed for a homogeneous membrane [23]; under certain restricted conditions, structural vibrations may actually starve turbulent eddies, leading to a reduction of the magnitude of the pressure fluctuations. A somewhat similar analysis was used to obtain similar conclusions [56]. These analyses are a step forward in the solution of a coupled problem because structural and fluid equations were solved simultaneously; analytical results for a plate or a more general elastic layer of finite thickness are not yet available, however. It has been shown experimentally [29] that forced low order surface vibrations -- much smaller than those of the laminar sublayer -- can alter the power spectral density of the axial turbulent velocity. Whether this conclusion is valid for pressure fluctuations or for self-excited vibrations remains an unanswered question.

Recent experimental results [9] indicate that the increase or decrease in the turbulent energy spectrum is dependent upon frequency and distance from the wall. In general, disturbances for compliant surfaces increase at lower frequencies and decrease at higher frequencies. In most cases the changes due to surface compliance diminish as the distance from the wall increases.

Results available to date thus indicate that, under certain restricted conditions, fluid-structure coupling may increase the stability of flow disturbances, thereby decreasing the Reynold turbulent stresses, surface drag, and the resulting pressure fluctuations. Conversely, under other conditions stability may be decreased. The conditions under which these predictions may be made is of course dependent upon the mathematical model adopted for the structure.

PROPELLER-INDUCED FORCES

Four general fluid-structure interaction problems are of interest in the field of propeller vibration and noise:

- flow noise due to flow field perturbations
- flow-induced vibrations of blades
- bearing forces due to thrust and torque fluctuations of blades
- surface forces caused by the pressure field surrounding propeller blades

Flow noise has two components: the fluid disturbance due to vortex shedding from the trailing edge of the blades and the component due to the blade cutting through an incoming turbulent flow field. The latter is of interest mostly to acousticians; a good review has been published [43]. As the fluid leaves the trailing edge of the blade, vortices are shed and induce a force on the blade that varies with time. If the excitation frequency of these forces -- excitation frequency is equivalent to vortex shedding frequency -- is equal to or close to any torsional mode, the blades will "sing." This phenomenon has been discussed [46].

Of special interest in ship vibration studies are the fluid-generated forces and moments transmitted by the blades to the ship hull via the structure (shaft) and the fluid. These forces and moments are caused by temporal and spatial variations in the incoming fluid. In practice, the spatial variation (circumferential) of the axial incoming flow field, or wake, dominates other nonuniformities in the flow field; e.g., radial variation of the axial incoming flow field, variations of radial and tangential velocity components. The circumferential variation of the incoming flow at a specific propeller radius changes the angle of attack of the blade elements as the propeller makes on revolution; periodic variations in blade-element loading or pressure distributions are thus created.

The forces transmitted to a bearing on a propeller shaft result from thrust and torque fluctuations experienced by each blade of the propeller. The only forces transmitted to the bearing of a perfectly balanced propeller are due to thrust and torque fluctuations. Fluctuations result from variations in the wake profile at the propeller blades. This phenomenon can be analyzed with a wing element model that moves rectilinearly through a cyclic gust pattern [11]. The problem of interest is the interaction between a nonuniform known flow field and the rigid surface of a moving body. This interaction can be written as

$$D_f[\bar{u}] = F(\bar{U}) + P \tag{47}$$

For a given wake function, $F(\bar{U})$, the interaction force P subject to the moving boundary condition must be evaluated. The frequency of the resulting force is a linear function of the number of blades,

the rpm of the propeller, and the spatial velocity variation. At low frequencies, the fluid is basically incompressible, and the fluid equation becomes Laplace's equation

$$\nabla^2 \phi = 0 \tag{48}$$

subject to the rigid surface condition of

$$\frac{\partial \phi}{\partial n} = 0 \tag{49}$$

on the blade surface.

The effects of blade thickness and skew have been studied. A theory that includes three dimensional unsteady flow, blade and helical wake geometry, and the distribution of ship wake has been shown to correlate well with experimental results [11]. Excellent reviews of the state-of-the-art for the different numerical techniques available to evaluate vibratory forces are also cited. Tsakonas, Jacobs, and Ali [52] have been instrumental in advancing the state-of-the-art. At high blade stiffnesses and relatively smooth wakes, structural frequencies are much larger than any fluid-related frequencies. The only loading that affects the propeller blades is due to the mass, which can be accurately determined with Laplace's equation. Under these conditions the forces are transmitted to the hull via the structure.

Surface forces are caused by the pressure field surrounding each blade as it sweeps past the ship's hull. These forces exist even for a homogeneous flow profile. The circumferential variations of the incoming axial flow field will add to the pressure fluctuations on the blades. Surface forces tend to become more important at higher frequencies and higher order surface modes. Disturbances under these conditions are transmitted more readily by the fluid. For such complex problems, the radiation loading term must be retained in the analysis. If the surface is rigid and its dimensions are large relative to the wavelength of the fluid flow, the pressure induced on the surface is twice the force that would be present if there were no surface. When the surface is assumed to be compliant, the more complex interaction problem, given above, is solved. The general interaction problem is given by

$$D_S[\bar{w}^*] = F(\bar{U}) + P(\bar{w}^*) \tag{50}$$

$$\nabla^2 \phi + k^2 \phi = 0 \tag{51}$$

$$\frac{\partial \phi}{\partial n} = \bar{w}^* \quad \text{on the surface.} \tag{52}$$

The state-of-the-art of the fluid path problem is at best sketchy; practical results are few and expensive. In some analyses [11, 54] the fluid is assumed to be incompressible (i.e., k=0); the structure is assumed to vibrate in its higher order modes, where the frequency of excitation plays an important role. This assumption is generally valid so long as the wavelength of the fluid flow is much longer than the wavelength of the structural vibration.

REFERENCES

1. Allik, H. and Hughes, T.J.R., "Finite Element Method for Piezoelectric Vibration," Intl. J. Numer. Methods Engr., 2, pp 151-157 (1970).

2. Allik, H., Cacciatore, P.J., Gauthier, R., and Gordon, S.F., "MARTSAM IV - A Version of GENSAM," General Dynamics, Electric Boat Division Report U440-74-043, Vols. I, II, III, IV (May 1974). (approval of NAVSEA required.)

3. Baylor, J.L., "Operator Singularities of Integral Equations of Linear Acoustics," J. Acoust. Soc. Amer., 42 (5), p 1204 (Nov 1967).

4. Belsheim, R.O. and O'Hara, G.J., "Shock Design of Shipboard Equipment," Part I (unclassified NAVSHIPS Rept. No. 250-423-30 (May 1961)).

5. Benjamin. B.T., "Effect of a Flexible Boundary on Hydrodynamic Stability," J. Fluid Mech., 9, pp 513-532 (1960).

6. Berger, B.S., "Reflected and Radiated Acoustic Pressure from an Elastic Shell of Revolution," Rept. Contract No. N00014-67-A0239-0020, Univ. Maryland (Oct 1975).

7. Bleich, H.H. and Baron, M.L., "Free and Forced Vibrations of an Infinitely Long Cylindrical Shell in an Infinite Acoustic Medium," J. Appl. Mech., Trans. ASME, 21, pp 167-177 (1954).

8. Bleich, H.H., DiMaggio, F.L., and Baron, M.L., "On Uncoupling Fluid-Structure Interaction Problems," Part II, Weidlinger Assoc. Rept. ONR Contract N00014-72-C-0119 (July 1973).

9. Blick, E.F., "Skin Friction Drag Reduction by Compliant Coatings," Paper F2, Intl. Conf. Drag Reduction, Cambridge (Sept 1974).

10. Boggs, F.W. and Frey, H.R., "The Effect of a Lamiflo Coating on a Small Planing Hull Having Zero Deadrise," U.S. Rubber Co. Rept. (June 1961).

11. Breslin, J.P., "Techniques for Estimating Vibratory Forces Generated by Propellers," Tech. Res. Bull. No. 1-34, Hydrodynamics Committee, Soc. Naval Architects Marine Engr. (1975).

12. Brown, R., "Turbulent Pressure Spectrum Measurements on a Compliant Surface," Fourth Biannual Symp. Turbulence in Liquids, Univ. Missouri-Rolla (Sept 1975).

13. Carrier, G.F., "The Interaction of an Acoustic Wave and an Elastic Cylindrical Shell," Tech. Rept. 4, Contract Nonr-35810, Brown Univ. (1951).

14. Chen, L.H., "A Matrix Method of Analysis of Structure-Fluid Interaction Problems," ASME Paper No. 61-WA-220 (Nov 1961).

15. Chen, L.H. and Schweikert, D.G., "Sound Radiation from an Arbitrary Body," J. Acoust. Soc. Amer., 35 (10), pp 1626-1632 (1963).

16. Davies, H.G., "Sound From Turbulent Boundary Layer Excited Panels," J. Acoust. Soc. Amer., 49 (3), pp 878-889 (1971).

17. DiMaggio, F.L., "Dynamic Response of Fluid-Filled Shells," Shock Vib. Dig., 7 (5), pp 5-12 (May 1975).

18. Dowell, E.H., "Noise or Flutter or Both?" J. Sound Vib., 11 (2), pp 159-180 (1970).

19. Engin, A.E. and Engin, A.W., "Survey of the Dynamic Response of Spherical and Spheroidal Shells," Shock Vib. Dig., 7 (3) (1975).

20. Everstine, G.C., Schroeder, E.M., and Marcus, M.S., "The Dynamic Analysis of Submerged Structures," Fourth NASTRAN Users Colloq., Langley Res. Ctr. (Sept 1975).

21. Farn, C.L.S. and Huang, H., "Transient Acoustic Fields Generated by a Body of Arbitrary Shape," J. Acoust. Soc. Amer., 43 (2), pp 252-257 (1968).

22. Feit, D., "Flow Noise Characteristics of Elastic Plates Excited by Boundary Layer Turbulence," Cambridge Acoust. Assoc. Rept. No. U-279-199 (Apr 1968).

23. Ffowcs-Williams, J.E., "Reynold Stress near a Flexible Surface Responding to Unsteady Air Flow," Bolt Beranek and Newman Rept. No. 1138 (June 1964).

24. Geers, T.L., "Residual Potential and Approximate M[illegible]s for Three Dimensional Fluid-Structu[illegible]ction Problems," J. Acoust. Soc. Amer., 49 [illegible], pp 1505-1510 (1971).

25. Hansen, R.J. and Hunston, D.L., "An Experimental Study of Turbulent Flows Over Compliant Surfaces," J. Sound Vib., 34 (3), pp 297-308 (1974).

26. Haviland, J.K. and Cooley, D.E., Structural Mechanics Computer Programs (W. Pilkey, K. Saezalski, and H. Schaeffer, Eds.), Univ. Virginia Press (1974).

27. Henderson, F.M., "A Structure-Field Interaction Capability for the NASA Structural Analysis (NASTRAN) Computer Program," DTNSRDC Rept. No. 3962 (Aug 1972).

28. Huang, H. and Wang, Y.F., "Early-Time Interaction of Spherical Acoustic Waves and a Cylindrical Elastic Shell," J. Acoust. Soc. Amer., 50, pp 885-891 (1971).

29. Izzo, A.J., "An Experimental Investigation of the Turbulent Characteristics of a Boundary Layer Flow over a Vibrating Plate," Dissertation submitted to Univ. Connecticut (1969).

30. Junger, M.C., "Vibrations of Elastic Shells in a Fluid Medium and the Associated Radiation of Sound," J. Appl. Mech., Trans. ASME, 19 (1) (Mar 1952).

31. Kalinowski, A.J., "Fluid Structure Interaction," in Shock and Vibration Computer Programs - Reviews and Summaries (W. and B. Pilkey, Eds.), Naval Res. Lab., Wash., D.C., pp 405-452 (1975).

32. Kline, R.G. and Daidola, J.C., "Ship Vibration Prediction Methods and Evaluation of Influence of Hull Stiffness Variation on Vibratory Response," Rept. SSC-249, Ship Struc. Comm., U.S. Coast Guard, Wash., D.C., pp 2-11 (1975).

33. Klosner, J.M., "Response of Shells to Acoustic Shocks," Shock Vib. Dig., 8 (5), pp 3-13 (1976).

34. Krämer, M.O., "Boundary Layer Stabilization by Distributed Damping," J. Amer. Soc. Nav. Engr., 72, p 25 (1960).

35. Landhal, M.T., "On the Stability of a Laminar Incompressible Boundary Layer over a Flexible Surface," J. Fluid Mech., 13 (1962).

36. Laufer, J. and Maestrello, L., "The Turbulent Boundary Layer over a Flexible Surface," The Boeing Co. Document No. D6-9708 (1963).

37. Leibowitz, R.D., "Vibroacoustic Response of Turbulence Excited Thin Rectangular Finite Plates in Heavy and Light Fluid Media," J. Sound Vib., 40 (4), pp 441-495 (1975).

38. Leibowitz, R.C., "Experimental and Theoretical Foundations for Modern Turbulence - Vibroacoustic Research. A Decade of Exploration 1956-1965," DTNSRDC Tech. Note SAD 536-194 (Nov 1975).

39. Lin, C.C., The Theory of Hydrodynamic Stability, Cambridge Univ. Press (1967).

40. McMahon, J.F., "Surface Wave Characteristics for the Flow of an Inviscid Fluid Over an Elastic Surface," Penn. State Univ., ORL Rept. No. TN502-02 (1970).

41. Menton, R.T. and Magrab, E.B., "Interaction of Acoustic Pulses with Fluid-Loaded Shell Structures," Shock Vib. Dig., 5 (12), pp 2-12 (1973).

42. Mnev, Y.N. and Pertsev, A.K., "Hydroelasticity of Shells," Air Force Systems Command Rept. FTD-MT-24-119-71 (1971).

43. Morfey, C.L., "Rotating Blades and Aerodynamic Sound," J. Sound Vib., 28 (3), pp 587-618 (1973).

44. Neubert, V.H., "Inertia Matrices for Finite Elements," Shock and Vibration Computer Programs - Reviews and Summaries (W. and B. Pilkey, Eds.), Naval Res. Lab., Wash., D.C., pp 625-645 (1975).

45. Pierucci, M., "Hydrodynamic Instabilities of a Layered Medium in the Presence of a Flow Field," J. Acoust. Soc. Amer., 58, p 521 (1975).

46. Ross, D., "Vortex Shedding Sounds of Propellers," Bolt Beranek and Newman Rept. No. 1115 (1964).

47. Schenck, H.A., "Improved Integral Formulation for Acoustic Radiation Problems," J. Acoust. Soc. Amer., 44 (1), pp 41-58 (July 1968).

48. Smith, R.R., Hunt, J.T., and Barach, D., "Finite Element Analysis of Acoustically Radiating Structures with Applications to Sonar Transducers," J. Acoust. Soc. Amer., 54 (5), pp 1277-1288 (1973).

49. Smith, R.R., Barach, D., McCleary, L.E., and Johnson, J.L., "A Finite Element Model for Analyzing Self-Noise Levels in Geophysical Towed Line Arrays," ASME Paper No. 76-PVP-27 (May 1976).

50. Strawderman, W.A., "Turbulence Induced Plate Vibrations: An Evaluation of Finite and Infinite Plate Models," J. Acoust. Soc. Amer., 46 (5), pp 1294-1307 (1969).

51. Tokita, N. and Boggs, F.W., "Final Report on Theoretical Study of Compliant Coatings to Achieve Drag Reduction on Underwater Vehicles," U.S. Rubber Co., Rept. No. NR062-241 (1962).

52. Tsakonas, S., Jacobs, W.R., and Ali, M.R., "An Exact Linear-Surface Theory for a Marine Propeller in a Non-Uniform Flow Field," J. Ship Res. (Dec 1973).

53. VonWinkle, W.A., "An Evaluation of a Boundary Layer Stabilization Coating," Underwater Sound Lab Memo No. 922-111-61 (1961).

54. Vorus, W.S., "An Integrated Approach to the Determination of Propeller-Generated Vibratory Forces Acting on a Ship Hull," Univ. Michigan Rept. No. 072 (1971).

55. Warburton, G.B., "Vibration of a Cylindrical Shell in an Acoustic Medium," J. Mech. Engr. Sci., 3, p 69 (1961).

56. White, F.M. and Quaglieri, R.E., "A Theoretical Estimate of Turbulent Wall Pressure Fluctuations on a Compliant Boundary," U.S. Navy Underwater Sound Lab. Rept. No. 767 (1966).

57. Zamyshiyayev, V.B. and Yakovelev, Y.S., "Dynamic Loads in Underwater Explosion," Rept. AD-757 183, NTIS, U.S. Dept. of Commerce, Springfield, VA (Feb 1973).

58. Zienkiewicz, O.C. and Newton, R.E., "Coupled Vibrations of a Structure Submerged in a Compressible Fluid," Proc. Intl. Symp. Finite Element Tech., Intl. Assoc. Ship Struc., Univ. Stuttgart, Ger. (June 1969).

BOOK REVIEWS

DESIGN OF ASEISMIC BUILDINGS AND STRUCTURES (PROEKTIROVANIE SEISMOSTOIKIKH ZDANII)

Edited by S. V. Polyakov

Izdatelstvo Literatury po Stroitelstvu, Moscow (1971)

The book represents the third of a series of four volumes (Vol. I: Seismic actions on buildings and structures; Vol. II: Bases of the theory of seismic resistance of buildings; Vol. IV: Design of earthquake resistant water power, transport, and special structures). It contains eight chapters.

Chapter I (S. Yu. Duzinkevich) deals with general aseismic design principles. It discusses the importance of earthquakes and of aseismic design and presents mainly qualitative design recommendations.

Chapter II (editor) deals with basic characteristics of building materials in case of dynamic loading. Influences of parameters such as cycle asymmetry, number of loading cycles, type of local stress state, stress concentration, etc., are discussed. Design recommendations are derived.

Chapter III (V.S. Pavlyk) deals with seismic design loading. Analysis is compared with observed effects. Bases of Soviet code recommendations are then presented (linear dynamic approach, use of response spectra). Practical design rules are then explained.

Chapter IV (Sh.A. Djabua, editor. A.L. Churayan) deals with bearing wall masonry structures. General remarks are followed by a summary of code recommendations. Character of failure of bearing walls is then discussed and many illustrative examples are given. Detailed recommendations are then given for various types of members. Some analysis patterns are then given.

Chapter V (editor, V.I. Konovodchenko) deals with large panel buildings. General remarks are followed by design recommendations. Standard constructive solutions used in USSR are then given. Composite systems are discussed. Problems of tall buildings are dealt with as are problems raised by a flexible first story. Analysis procedures are recommended.

Chapter VI (F.V. Bobrov) deals with reinforced concrete frame buildings. General remarks are followed by discussion of segmentation of precast frames. Joints are discussed, analysis procedures are given.

Chapter VII (A.I. Martem'yanov) deals with timber constructure. General remarks are followed by a qualitative discussion of design solutions.

Chapter VIII (Sh. A. Djabua, A.L. Churayan) deals with use of prestressed concrete. General remarks are followed by presentation of some actual buildings.

The volume represents, like the other volume of the series, a compendium of Soviet experience and a guide and handbook for design. It corresponds to theoretical bases introduced in actual Soviet code and has a practical character. Its content is of direct interest for specialists of aseismic design.

H. M. Sandi, Romania

Courtesy of Applied Mechanics Reviews

ACOUSTICS AND VIBRATION PROGRESS, VOLUME 1

Edited by R. W. B. Stephens and H. G. Leventhal
Halsted Press, New York (1974)

This book is the first in a new series that is "designed to encompass, during the course of three or four years, the basic acoustical areas of significance with the introduction of emerging topics of importance as they arise." The volume contains five chapters, a brief outline of which is given below.

In the first chapter, "Traffic Noise," by M. E. Delany of the National Physical Laboratory at Teddington, the noise due to individual vehicles and to streams of vehicles is surveyed. The effects of flow rate, speed, road grade, mix of vehicles, and other parameters are given in detail. Propagation and its prevention are also discussed. Most of the 68 references are British.

The second chapter "Acoustic Emission," By A. A. Pollock of Dunegan/Endevco in England, describes the development of and motivation for acoustic emission techniques. Recent progress in the materials understanding, signal processing, transducers, analytical models, experimental technique, and applications is reviewed.

"Chemical Aspects of Ultrasonics," by A. Śliwiński of the University of Gdańsk in Poland, reviews the study of chemical reactions in an ultrasonic field. Effects and processes stimulated by ultrasonics -- e.g., electrochemical influences, cleaning and extraction processes in high intensity fields, and the use of ultrasonic-spectroscopy to investigate chemical structure -- are also reviewed. This chapter contains the most extensive coverage; 244 references are given.

"Vibration and Noise Transmission in Buildings," by H. M. Nelson of the University of Sydney in Australia, briefly reviews transmission loss theory and elements of (classical) wave propagation. Modal density and statistical energy analysis concepts are also briefly discussed. Nelson lists 91 references.

Chapter 5, "Underwater Ambient Noise," by E. M. Arase and T. Arase of Stevens Institute of Technology, reviews the mechanisms that create underwater noise. These include wind, traffic, flow noise, and atmospheric sources. Attention is also paid to directionality, in terms of measurements and causes, and to statistical aspects; 83 references are given.

On the whole, the reviews are well written and informative. Some of the articles are more comprehensive than others. The subject of the fourth chapter (by Nelson), in this reviewer's opinion, deserved a deeper and longer discussion.

The editors have taken their job seriously and in doing so have gotten their new series off to a good start.

Dr. Clive Dym
Bolt Beranek & Newman
50 Moulton St.
Cambridge, MA 02138

SHORT COURSES

AUGUST

NOISE CONTROL IN ENGINEERING

Dates: August 8 - 12, 1977

Place: University of Michigan, Ann Arbor

Objective: Risk of hearing damage from factory noise (e.g., OSHA regulations) and excessive product noise (e.g., EPA regulations) constitute serious concerns for industry. This course provides engineers and managers with comprehensive knowledge of noise control engineering and criteria for application to practical problems.

Contact: Engineering Summer Conferences, 200 Chrysler Center, North Campus, The University of Michigan, Ann Arbor, MI 48109

STATIC AND DYNAMIC FINITE ELEMENT ANALYSIS WITH COMPUTER WORKSHOP

Dates: August 8 - 12, 1977

Place: MIT, Cambridge, Massachusetts

Objective: The objective in this program is to present the essential details of selecting an appropriate finite element model, analyzing the model, and interpreting the results. This is achieved by a coordinated set of lectures and a computer workshop.

Contact: Office of the Summer Session, Rm E19-356, Massachusetts Institute of Technology, Cambridge, MA 02139, Tele. (617) 253-2101

IMPEDANCE AND DYNAMIC ANALYSIS OF STRUCTURES

Dates: August 15 - 19, 1977

Place: State College, PA

Objective: To present measurement and analysis techniques by which impedance, transfer, and impulse functions are used directly in prediction of structural response to ground motion or pressure loading, in fluid-structure interaction, in identifying modal properties of structures, and in arriving at finite element models.

Contact: Dr. V. H. Neubert, 133 Hammond Bldg., The Pennsylvania State University, University Park, PA 16802, Tele. (814) 865-6161

THE SCIENTIFIC AND MATHEMATICAL FOUNDATIONS OF ENGINEERING ACOUSTICS

Dates: August 15 - 26, 1977

Place: MIT, Cambridge, Massachusetts

Objective: This program is a specially developed course of study which is based on two regular MIT subjects (one graduate level and one undergraduate level) on vibration and sound in the Mechanical Engineering Department. The program emphasizes those parts of acoustics -- the vibration of resonators, properties of waves in structures and air -- the generation of sound and its propagation that are important in a variety of fields of application. The mathematical procedures that have been found useful in the processing of data are also studied.

Contact: Richard H. Lyon, Massachusetts Institute of Technology, Rm. 3-366, Dept. of Mech. Engrg., Cambridge, MA 02139

COMPUTER GRAPHIC, NASTRAN, AND FINITE ELEMENT METHOD

Dates: August 1 - September 15, 1977

Place: San Francisco, CA/Washington, D.C.

Objective: A sequence of three professional development courses will be presented to provide an understanding of the technological content in general purpose finite element programs; and to provide training in the use of NASTRAN. Dates are:

San Francisco:

- Finite Element Method - August 1 - 5
- Static and Normal Modes Analysis using NASTRAN - August 8 - 11
- Dynamic and Nonlinear Analysis using NASTRAN - August 15 - 18

Washington, D.C.:

- DMAP NASTRAN Programming - August 23 - 26
- NASTRAN System Programming - August 29 - 31
- Interactive Computing and Graphics - September 12 - 15

Contact: Dr. H. Schaeffer, Schaeffer Analysis, P.O. Box 761, Berwyn Station, College Park, MD 20740 Tele. (301) 721-3788

INTRODUCTION TO VIBRATION AND SHOCK SURVIVABILITY, TESTING, MEASUREMENT, ANALYSIS AND CALIBRATION

Dates: August 22 - 26, 1977
Place: Santa Barbara, California
Objective: To provide basic education in resonance and fragility phenomena, in vibration and shock environmental measurement and analysis, also in vibration and shock testing to prove reliability. This course will concentrate upon equipments and techniques rather than upon theory. Mathematics is avoided where possible.

Contact: Mr. W. Tustin, Tustin Institute of Technology, Inc., 22 E. Los Olivos St., Santa Barbara, CA 93105, Tele. (805) 963-1124

CORRELATION AND COHERENCE ANALYSIS FOR ACOUSTICS AND VIBRATION PROBLEMS

Dates: August 29 - September 2, 1977
Place: UCLA, Los Angeles, California
Objective: This course covers the latest practical techniques of correlation and coherence analysis -- ordinary, multiple, and partial -- for solving acoustics and vibration problems in physical systems.

Contact: Continuing Education in Engineering and Mathematics, Short Courses, 6266 Boelter Hall, UCLA Extension, Los Angeles, CA 90024, Tele. (213) 825-1047

SEPTEMBER

FINITE ELEMENT ANALYSIS WORKSHOP

Dates: September 29 & 30, 1977
Place: Chicago, Illinois
Objective: This course covers the finite element modeling of machines and structures. The theory and practice of the finite element method will be discussed along with pertinent examples and case histories. Participants will be able to work their own problems.

Contact: Dr. Ronald L. Eshleman, Vibration Institute Suite 206, 101 W. 55th St., Clarendon Hills, Illinois 60514, Tele. (312) 654-2254/654-2053

OCTOBER

VIBRATION CONTROL

Dates: October 10 - 14, 1977
Place: The Pennsylvania State University
Objective: Topics for consideration include dynamic mechanical properties of viscoelastic materials; structural damping; isolation of machinery vibration from rigid and nonrigid sub-structures; suppression of rotating machinery vibration; hardware for vibration isolation; isolation of impact transients; reduction of vibration in beams, plates, shells, and periodic structures; sandwich beams and plates; instrumentation for vibration measurements; reduction of the flow-induced vibration of complex structures; and characteristics of multi-resonant vibrations. Each student will receive bound lecture notes and copies of five textbooks for his permanent reference.

Contact: Prof. J. C. Snowdon, Seminar Chairman, Applied Research Lab., The Pennsylvania State Univ., P.O. Box 30, State College, PA 16801

MACHINERY VIBRATION SEMINAR

Dates: October 25 - 27, 1977
Place: MTI, Latham, New York
Objective: To cover the basic aspects of rotor-bearing system dynamics. The course will provide a fundamental understanding of rotating machinery vibrations; an awareness of available tools and techniques for the analysis and diagnosis of rotor vibration problems; and an appreciation of how these techniques are applied to correct vibration problems. Technical personnel who will benefit most from this course are those concerned with the rotor dynamics evaluation of motors, pumps, turbines, compressors, gearing, shafting, couplings, and similar mechanical equipment. The attendee should possess an engineering degree with some understanding of mechanics of materials and vibration theory. Appropriate job functions include machinery designers; and plant, manufacturing, or service engineers.

Contact: Mr. P. E. Babson, Mktg. Mgr., Machinery Diagnostics, MTI, 968 Albany-Shaker Rd., Latham NY 12110, Tele. (518) 785-2371

NEWS BRIEFS

news on current and Future Shock and Vibration activities and events

EIGHTH U.S. NATIONAL CONGRESS OF APPLIED MECHANICS

CALL FOR ABSTRACTS

The 8th U.S. National Congress of Applied Mechanics will be held June 26-30, 1978 on the campus of the University of California at Los Angeles. The general plan for the program includes (1) 4 general lectures by distinguished invited speakers, (2) 15 invited lectures; surveys or original work by both senior and younger people, and (3) contributed papers. The invited lectures will be roughly one hour presentations.

The contributed papers will all be ten minute presentations. A member of any of the ten societies that are organizing the congress (which are the ten societies represented on the U.S. National Committee for Theoretical and Applied Mechanics) may submit an abstract and give such a ten minute presentation on his work. Further, a nonmember may make a similar presentation by submitting his abstract through a member of one of the societies. Deadline for the abstracts is December 31, 1977. The should be sent to:

Professor Julian D. Cole
Mechanics and Structures Department
School of Engineering and Applied Science
University of California, Los Angeles
Los Angeles, CA 90024

The abstracts should have the form of those for the American Physical Society meetings (cf. any issue of the bulletin of that society).

It is planned that abstracts of the invited lectures and contributed papers will be published, to be available before the meeting. For further information contact Professor Cole at the above address.

SYMPOSIUM ON FUTURE TREND IN COMPUTERIZED STRUCTURAL ANALYSIS AND SYNTHESIS

CALL FOR PAPERS

The purpose of the symposium to be held October 30 thru November 1, 1978, at the Mariott Hotel at Twin Bridges, Washington, D.C., is to provide multidisciplinary medium for communicating recent and projected advances in computer hardware, software, numerical analysis, applied mechanics and their application to future structural analysis and synthesis systems.

Authors should submit three copies of an extended abstract of about 1,000 words including sample figures prior to September 30, 1977. Notification of acceptance will be given by November 25, 1977. Three copies of the final manuscript, complete with original drawings or glossy prints will be due by April 7, 1978.

One page abstracts are also solicited on current research in progress for short presentations at special sessions. A volume of Proceedings will be published before the meeting and the papers accepted will also be considered for publication in the Journal of Computers and Structures. For further information, please contact:

Professor Ahmed K. Noor
MS-246
GWU-NASA Langley Research Center
Hampton, Virginia 23665
Telephone: (804) 827-2897

CHANGE OF DATES FOR NOISE-CON 77

The dates for NOISE-CON 77, the 1977 National Conference on Noise Control Engineering, to be held in San Francisco, have been changed to 17-19 October 1977. This change (from 10-12 October 1977) has been made to avoid starting the meeting on Columbus Day which is a Federal holiday.

ABSTRACTS FROM THE CURRENT LITERATURE

Copies of articles abstracted in the DIGEST are not available from the SVIC or the Vibration Institute (except those generated by either organization). Inquiries should be directed to library resources. Government reports can be obtained from the National Technical Information Service, Springfield, VA 22151, by citing the AD-, PB-, or N- number. Doctoral dissertations are available from University Microfilms (UM), 313 N. Fir St., Ann Arbor, MI; U. S. Patents from the Commissioner of Patents, Washington, D.C. 20231. Addresses following the authors' names in the citation refer only to the first author. The list of periodicals scanned by this journal is printed in issues 1, 6, and 12.

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ANALYSIS AND DESIGN

ANALYTICAL METHODS

(Also see No. 1266)

77-1236

Some Applications of Stochastic Methods in Research on Vibrational Phenomena

J.W.G. VanNunen
Fluid Dynamics Div., National Aerospace Lab., Amsterdam, The Netherlands, Rept. No. NLR-MP-75040-U, 12 pp (Nov 10, 1975)
N77-16384

Key Words: Stochastic processes, Flutter, Aircraft wings, Bridges, Towers

The use of stochastic methods in determining natural frequencies and corresponding damping of structures is demonstrated for flutter analysis of a wing model, vibration analysis of a traffic bridge, and vibration analysis of a high voltage mast.

77-1237

Response of Three Oscillators Coupled by a Weak Nonlinearity

N. Yen and R.E. Kronauer
Naval Underwater Systems Ctr., New London, CT 06320, J. Appl. Mech., Trans. ASME, 99 (1), pp 141-146 (Mar 1977) 1 fig, 12 refs

Key Words: Resonant response, Coupled response

As a simplified model of the exchange processes occurring among resonance modes in physical systems, such as a piezoelectric crystal plate or an acoustic interferometer, a study is made of the response of three oscillators that are coupled by a weak nonlinearity and whose frequencies satisfy the condition $\omega_1 + \omega_2 \cong \omega_3$. The transient behavior is obtained by a perturbation expansion. There exist three integral constraints on the amplitude and phase variation of the oscillations for a conservative system, and the solution of the response is reduced to quadrature. For nonconservative systems, the effects of dissipation and detuning are examined for their role in limiting the energy exchange among the oscillations and in determining the steady-state response to forcing. Predictions from this analysis are compared with results of a reported experiment in which a piezoelectric crystal plate is forced to oscillate at amplitudes sufficient to generate coupled subharmonics.

77-1238

Determination of Global Regions of Asymptotic Stability for Difference Dynamical Systems

C.S. Hsu, H.C. Yee, and W.H. Cheng
Dept. of Mech. Engrg., Univ. of California, Berkeley, CA, J. Appl. Mech., Trans. ASME, 99 (1), pp 147-153 (Mar 1977) 5 figs, 10 refs
Sponsored by NSF

Key Words: Dynamic systems, Difference equations

In this paper certain global properties of dynamical systems governed by nonlinear difference equations are studied. When an asymptotically stable equilibrium state or periodic solution exists, it is desirable to be able to determine a global region of asymptotic stability in the state space. In this paper an effective method is presented for the determination of such a region. The method is mainly presented for second-order systems but the basic ideas are also applicable to higher-order systems. Through the development of the theory and examples, one also sees that, in general, the region of asymptotic stability for a nonlinear difference system is of extremely complex shape.

NUMERICAL ANALYSIS

77-1239

Numerical Fourier Analysis in the Range of Higher Frequencies

J.F. Ury
Faculty of Mech. Engrg., Technion--Israel Inst. of Tech., Haifa, Israel, Intl. J. Numer. Methods Engr., 11 (3), pp 469-480 (1977) 2 figs, 7 refs

Key Words: Spectrum analysis, Numerical analysis, Fourier analysis, Diesel engines

A novel method is proposed for the numerical computation of Fourier coefficients in the range of higher frequencies for which hitherto no practical method was available. The accuracy of the results obtained by application of this method is discussed, and bounds of a correction term are determined accordingly. An example from the field of Diesel engine research is given, and the computed spectrum is compared with the spectrum recorded by an electronic harmonic analyzer.

OPTIMIZATION TECHNIQUES

(Also see No. 1268)

77-1240

Optimum Design of Structures with Regard to Their Vibrational Characteristic (Second Report, The Type-1-Problems of Structural Elements Having 1-Section-Freedom and 2-Section-Freedom)

H. Yamakawa and A. Okumura

School of Science and Engrg., Waseda Univ., Shinjuku-ku, Tokyo, Japan, Bull. JSME, 20 (141), pp 292-299 (Mar 1977) 21 figs, 2 tables, 4 refs

Key Words: *Structural members, Optimization*

In this report some demonstrative applications of a general method for optimum design of structures in which natural frequencies have been involved is shown. Numerical results obtained in the applications are discussed in detail.

77-124[illegible]

Optim[illegible] Design of Structures with Regard to Their Vibrational Characteristic (Third Report, The Type-2-Problems of Rods and Cantilevers, and Reciprocal Relation between Two Basic Types of Problems)

H. Yamakawa and A. Okumura

School of Science and Engrg., Waseda Univ., Shinjuku-ku, Tokyo, Japan, Bull. JSME, 20 (141), pp 300-306 (Mar 1977) 12 figs, 4 tables, 4 refs

Key Words: Optimization, Rods, Cantilever beams

In this report the problem of finding the optimum shapes of structures which give minimum total mass under specified fundamental frequencies is treated numerically. In addition a general method of optimum design of structures in which natural frequencies are involved in objective functions and/or conditions of constraints is demonstrated. An example of vibrating rods and cantilevers with a point mass is worked.

STABILITY ANALYSIS

77-1242

Stability Analysis for Linear Systems with Time Delays

L.K. Barker and J.L. Whitesides

NASA Langley Res. Ctr., Hampton, VA 23665 J. Sound Vib., 51 (1), pp 7-21 (Mar 8, 1977) 3 figs, 15 refs

Sponsored by NASA

Key Words: Stability analysis, Linear systems

Time delays in the mathematical description of a physical system occur whenever the system is affected not only be conditions at the present time, but also by conditions which have occurred in the past. The τ-decomposition method, as refined by Lee and Hsu, is a method for studying the effects of time delay on the stability of retarded dynamical systems. In this paper, the method is extended to examine the stability and relative stability of retarded systems with many time delays, and a class of neutral systems with one delay. Applications are included which illustrate the power of the technique.

FINITE ELEMENT MODELING

(Also see Nos. 1316, 1329, 1353)

77-1243

A Combined Finite Element-Transfer Matrix Structural Analysis Method

T.J. McDaniel and K.B. Eversole

Dept. of Aerospace Engrg. and Engrg. Res. Inst., Iowa State Univ., Ames, IA 50010, J. Sound Vib., 51 (2), pp 157-169 (Mar 22, 1977) 6 figs, 5 tables, 32 refs

Sponsored by the Engrg. Res. Inst. of Iowa State Univ., and the National Science Foundation

Key Words: Finite element technique, Transfer matrix methods, Stiffened structures, Computer programs

A combined finite element-transfer matrix (FETM) method is developed to study the dynamics of orthogonally stiffened structures. Finite element procedures are used in FETM to formulate transfer matrices for structural components which are not one-dimensional. The resulting transfer matrices are used to reduce the large number of unknowns occurring in a standard finite element analysis by obtaining transfer matrix relationships over large units of the structure. A reduction in computer storage and computation time is obtained since the dimension of the final matrix equation to be solved is considerably reduced. The accuracy of the FETM results are verified by comparison with an exact solution to the limiting modes and frequencies of a periodically stiffened structure of infinite length. A reduction of computer time was demonstrated for the FETM by a comparison with the SAP-4 finite element program. The efficiency of the FETM method was further demonstrated by computing the frequency response of a two row-five span orthogonally stiffened plate structure using ordinary transfer matrix procedures.

77-1244

Finite Element Analysis of Non-Linear Static and Dynamic Response

D.P. Mondkar and G.H. Powell
Div. of Struc. Engrg. and Struc. Mechanics, Dept. of Civil Engrg., Univ. of California, Berkeley, CA,
Intl. J. Numer. Methods Engr., 11 (3), pp 499-520 (1977) 9 figs, 44 refs

Key Words: Finite element technique, Computer programs, Nonlinear response

The paper presents the theoretical and computational procedures which have been applied in the design of a general purpose computer code for static and dynamic response analysis of non-linear structures. A general formulation of the incremental equations of motion for structures undergoing large displacement finite strain deformation is first presented. The results of analysis of a few non-linear structures are briefly discussed.

MODELING

(Also see Nos. 1258, 1355, 1376)

77-1245

An Impact Moment Coefficient for Vehicle Collision Analysis

R.M. Brach
Univ. of Notre Dame, Notre Dame, IN,
SAE Paper No. 770014, 12 pp, 4 figs, 13 refs

Key Words: Collision research (automotive), Mathematical models

Many investigators have used the equations of impulse, momentum and energy to analyze the changes in velocities when two vehicles collide. The equations generally include the classical coefficient of restitution which is used as a measure of energy loss. These equations and the coefficient are based upon large forces and short-duration contact between the two bodies. In this paper the equations of impact of two vehicles are derived including the moment impulse. An impact moment coefficient is defined. The value of this coefficient determines the extent to which a moment is developed between the two vehicles during impact. Two examples are presented.

PARAMETER IDENTIFICATION

77-1246

Recursive Least-Squares Time Domain Identification of Structural Parameters

P. Caravani, M.L. Watson, and W.T. Thomson
Dept. of Mech. and Environ. Engrg., Univ. of Calif., Santa Barbara, CA,
J. Appl. Mech. Trans. ASME, 99 (1), pp 135-140 (Mar 1977) 5 figs, 13 refs

Key Words: Parameter identification, Buildings, Seismic response

A method of identifying structural parameters such as damping and stiffness of a building from its time response under dynamic excitation is presented. A least-squares recursive computer algorithm which requires no matrix inversion is developed and tested with the response of a two-degree-of-freedom structure including Gaussian white noise. The algorithm provides means to account for both the model uncertainty and the investigators' confidence in the initial guess of the parameters. These statistical quantities can be updated with passage of time.

CRITERIA, STANDARDS, AND SPECIFICATIONS

77-1247

Noise Standards for Aircraft Type Certification (Modifications to FAR Part 36)

W.C. Sperry and D.C. Gray
Office of Noise Abatement and Control, Environ. Protection Agency, Washington, D.C.,
Rept. No. EPA/550/9-76/013, 293 pp (Aug 1976)
PB-262 401/3GA

Key Words: Aircraft noise, Noise reduction, Regulations

This document presents and discusses the background data used by the EPA in the development of proposed noise control regulations for promulgation by the FAA in conformance with the Noise Control Act of 1972. The proposed regulations pertain to control of airplane noise at the source and would amend the existing Federal Aviation Regulations Part 36 (FAR 36).

77-1248

Background Document for Medium and Heavy Truck Noise Emission Regulations

Office of Noise Abatement and Control, Environ. Protection Agency, Washington, D.C.,
Rept. No. EPA/550/9-76/008, 411 pp (Mar 1976)
PB-262 007/8GA

Key Words: Trucks, Noise generation, Regulations

On March 31, 1976, the Environmental Protection Agency issued a regulation governing noise emissions from medium and heavy trucks. That regulation was issued under Section 6 of the Noise Control Act of 1972. This document presents and discusses the background data used by the Agency in setting the standards contained in the regulation. Presented is a comprehensive exposition on the most up-to-date available information on the environmental, technological, and economic aspects of medium and heavy truck noise.

77-1249
Costs of Reinforcing Existing Buildings and Constructing New Buildings to Meet Earthquake Codes
R.D. Larrabee and R.V. Whitman
Dept. of Civil Engrg., Massachusetts Inst. of Tech., Cambridge, MA, Rept. No. MIT-CE-R76-25, 90 pp (June 1976)
PB-259 187/9GA

Key Words: Buildings, Earthquake resistant structures, Standards and codes

The costs of constructing new buildings to seismic codes are reviewed. A particular building, designed with and without seismic load is examined; design for seismic load increased with total cost 2.8 percent. Some impacts of the implementation of a new seismic code are discussed. Methods of reinforcing existing buildings are discussed. Estimated costs for reinforcing 156 buildings are presented.

SURVEYS AND BIBLIOGRAPHIES

77-1250
Air Bag Restraints (Citations from the Engineering Index Data Base)
M.E. Young
National Technical Information Service, Springfield, VA, 78 pp (Feb 1977) (see also NTIS/PS-77/0049)
NTIS/PS-77/0050/3GA

Key Words: Air bags (safety restraint systems), Bibliographies, Motor vehicles, Automobiles, Collision research (automotive)

Studies on all aspects of inflatable restraints for motor vehicles are presented in these articles from worldwide literature. Included are citations of articles on the feasibility, development, and testing of these safety devices for both standard and compact cars.

77-1251
Air Bag Restraints
(Citations from the NTIS Data Base)
M.E. Young
National Technical Information Service, Springfield, VA, 102 pp (Feb 1977)(Supersedes NTIS/PS-76/0024, and NTIS/PS-75/130)
NTIS/PS-77/0049/5GA

Key Words: Air bags (safety restraint systems), Bibliographies, Motor vehicles, Automobiles, Collision research (automotive)

Inflatable restraints used as safety devices in motor vehicles are described in these Federally-funded reports abstracted in the bibliography. The feasibility, development, and testing of the devices for both standard and compact cars are included.

MODAL ANALYSIS AND SYNTHESIS

(See Nos. 1412, 1414)

COMPUTER PROGRAMS

GENERAL

(Also see Nos. 1243, 1244, 1312, 1384, 1399)

77-1252

Dynamics and Stability of Lifting Parachutes

D.P. Saari

Ph.D. Thesis, University of Minnesota, 209 pp, 1976
UM 77-6999

Key Words: Parachutes, Mathematical models, Computer programs

A dynamic model is formulated which is capable of describing the three-dimensional motion of a general parachute-load system with general initial conditions, and a method is presented for determining five components of aerodynamic force and moment as functions of general angles of attack *in three-dimensional motion. Wind tunnel measurements* of the aerodynamic coefficients for a lifting parachute made at a Reynolds number of 5.5×10^5 are presented. The dynamic model is arranged in a computer program which provides a complete description of the motion of a parachute-load system initially released from an aircraft in level flight. The computer solution is capable of studying the effect of atmospheric winds prescribed in any manner as functions of time and altitude during the inflation and descent of the parachute. Several sample calculations are made, incorporating aerodynamic coefficients of axisymmetric and lifting parachutes and simulating planar motion as well as responses to transverse wind gusts.

77-1253

FCAP - A New Tool for the Performance and Structural Analysis for Complex Flexible Aircraft with Active Control

L. Morino and R.B. Noll

Dept. of Aerospace Engrg., Boston Univ., Boston, MA 02215, Computers and Struc., 7 (2), pp 275-282 (Apr 1977) 8 refs

Key Words: Aircraft, Computer programs

A very general formulation has been developed for the analysis of complex flexible-aircraft configurations in presence of active control. The formulation is incorporated into a computer program, Flight Control Analysis Program, which is designed in a modular fashion to incorporate aircraft dynamics and aerodynamics for complex configurations, as well as sensor, actuator and control logic element dynamics. Formulation of the total aircraft dynamic system is accomplished in matrix form by casting equations in state vector format. The system stability and performance are determined in either the frequency or time domain using classical analysis techniques. Fully unsteady aerodynamics is used for the evaluation of the flutter characteristics as well as the gust response of the aircraft.

77-1254

CRASH 2 User's Manual

R.R. McHenry and J.P. Lynch

Calspan Corp., Buffalo, NY, Rept. No. CALSPAN-ZQ-5708-v-4, DOT-HS-802 106, 86 pp (Nov 1976)
PB-262 822/0GA

Key Words: Computer programs, Collision research (automotive)

The CRASH computer program is an accident investigation aid aimed at achieving improved accuracy and uniformity in the interpretation of physical evidence from automobile accidents. The program can provide estimates of impact speeds and speed changes on the basis of two separate analytical techniques. Users may run the program in a timeshare interactive mode or in a batch processing mode. This report contains detailed instructions for users of the CRASH computer program.

77-1255

A Simulation Program for Large Dynamic Deformation of Vehicles

I.K. McIvor

Univ. of Michigan, SAE Paper No. 770054, 12 pp, 9 figs, 9 refs

Key Words: Computer programs, Collision research (automotive)

This paper describes the program UMVCS-1 which was developed for the computer simulation of vehicle crash. The program is based on a modular concept designed to give the user maximum flexibility in model synthesis. For a given simulation the user specifies the vehicle through an alphanumeric "physical description" of his model. Modeling elements include both finite element beams and mechanisms which are three dimensional generalizations of "resistances" commonly used in one dimensional simulations. Program capability is illustrated through the analysis of an actual vehicle crash test.

77-1256
Dynamic Analysis of Machinery via Program DYMAC
B. Paul
Mech. Engrg. and Applied Mechanics Dept., Univ. of Pennsylvania, SAE Paper No. 770049, 16 pp, 9 figs, 11 refs

Key Words: Computer programs, Ride dynamics, Road roughness, Ground vehicles

This paper described a computer program -- DYMAC -- which finds displacements, velocities, and accelerations in planar machinery subjected to forces of a virtually unrestricted nature. The user may also specify the motion of any parts of the system (e.g. speed of a crankshaft), and prescribe general relationships between the motions of different points in the sytem, as illustrated by an example of a spring-suspended vehicle moving over a rough road. It is shown how the information which describes the geometric, inertial, and topological properties of the system must be organized. Readers should be able to determine if DYMAC will serve their needs.

77-1257
Simulation of a Vehicle Suspension with the ADAMS Computer Program
N. Orlandea and M.A. Chace
SAE Paper No. 770053, 13 pp, 11 figs, 10 refs

Key Words: Computer simulation, Suspension systems (vehicles), Computer programs

This paper describes a computer simulation of the front suspension of a 1973 Chevrolet Malibu using the Automatic Dynamic Analysis of Mechanical Systems – ADAMS. The model was proposed by the SAE Fatigue Design and Evaluation Committee for evaluating the speed, economy and accuracy of various computer simulations in predicting displacements and loads in a suspension system. A comparison between experimental and simulated results is given.

77-1258
Simulation of Bond Graphs on Minicomputers
J.J. Van Dixhoorn
Measurement, Control and Systems, Engrg., Agricultural Univ., Wageningen, The Netherlands, J. Dyn. Syst., Meas. and Control, Trans. ASME, 99 (1), pp 9-14 (Mar 1977), 17 figs, 9 refs

Key Words: Computer programs, Bond graph technique, Mathematical models

A need exists for inexpensive interactive simulation of nonlinear bond graphs. Procedures are stated for writing the input structure table and for remedying some often occurring causal conflicts and algebraic loops. Examples are given of hands-on simulation using the THTSIM language, written for PDP-11 minicomputers.

ENVIRONMENTS

ACOUSTIC

(Also see Nos. 1248, 1352, 1377, 1385, 1386, 1397)

77-1259
The Measurement of Sound Absorption Coefficient in Situ by a Correlation Technique
K.A. Hollin and M.H. Jones
Dept. of Pure and Applied Physics, Univ. of Manchester, Inst. of Science and Tech., Manchester, UK, Acustica, 37 (2), pp 103-110 (Mar 1977) 11 figs, 11 refs

Key Words: Acoustic absorption, Correlation techniques

It has in the past proved difficult to obtain meaningful values for absorption coefficient in situ. The methods available involve either dismounting the material and testing a sample in the laboratory or substituting an "identical" sample for the test. The method to be described, using a correlation process, shows that results can be obtained in situ. Values of absorption coefficient have been obtained over a wide range of frequencies for several materials. The method can be used to measure the absorption behavior of a material in situ which it would otherwise be difficult to estimate, especially in the presence of background noise.

77-1260
Bounds on Phase Velocities of Guided Modes in Open Waveguides
B. Rulf and M. Bareket
Applied Mathematics Div., Tel Aviv Univ., Tel Aviv, Israel, J. Sound Vib., 50 (4), pp 509-517 (Feb 22, 1977) 8 refs
Sponsored by the National Res. Council of Canada, Ottawa

Key Words: Waveguide analysis, Eigenvalue problems, Elastic waves

Guiding of waves along cylinders with a surface impedance or along low velocity sound channels lead to eigenvalue problems in unbounded domains. Variational and comparison methods are used to find bounds on the discrete eigenvalues, which are related to the phase velocities of the guided modes. The variational methods yield upper bounds only, but they can be applied systematically to a large class of problems. The comparison methods yield upper and lower bounds, but are restricted to a smaller class of problems.

77-1261

Estimation of the Maximum Discrete Frequency Noise from Isolated Rotors and Propellers

Engrg. Sciences Data Unit, Ltd., London, UK, Rept. No. ISBN-0-85679-157-1, 12 pp (Sept 1976) ESDU-76020

Key Words: Aircraft propellers, Rotary wings, Sound pressures

A method of estimating the peak harmonic sound pressure levels from isolated rotors and propellers is given. The data are based on static measurements, mostly from rigs, from which the effect of ground reflection has been removed. Figures provide components of the first harmonic sound pressure level in terms of non-dimensional parameters. Arithmetic summation of these components gives an estimate of the first harmonic sound pressure level. Also provided are corrections which should be added to the first harmonic sound pressure level to obtain estimates of higher harmonic sound pressure levels.

77-1262

Jet Engine Noise Source Location: The Polar Correlation Technique

M.J. Fisher, M. Harper-Bourne, and S.A.L. Glegg
Inst. of Sound and Vibration Res., Univ. of Southampton, Southampton S09 5NH, UK, J. Sound Vib., 51 (1), pp 23-54 (Mar 8, 1977) 16 figs, 8 refs

Key Words: Jet noise, Engine noise, Noise source identification, Polar correlation technique

The objective of this paper is to introduce a new method of source location for use in aero-engine noise research. The technique, termed "polar correlation," employs an array of far field microphones which are normally located on a polar arc centred on the jet nozzle. The potential of this method is illustrated by examples of test results for full size jet engines and model jets. Certain fundamental and philosophical difficulties involved in the general use of this and other far field source location methods are also reviewed in some detail.

77-1263

Noise from Road Traffic (Interrupted Flow)

D. Gilbert
Dept. of Civil Engrg., Imperial College of Science and Tech., London SW7 2AZ, UK, J. Sound Vib., 51 (2), pp 171-181 (Mar 22, 1977) 2 figs, 5 tables, 2 refs

Key Words: Traffic noise

An equation for predicting L_{10} levels in urban streets has been derived from an analysis of measurements made at 190 sites in Edinburgh and elsewhere. The validity of the equation has been confirmed by an analysis of 134 measurements made in Sheffield and Rotherham. This equation included traffic variables which are at present difficult to predict, and an alternative equation that uses easily predictable variables has been derived from the Sheffield and Rotherham data. The standard errors of the two prediction methods were almost 3dB(A).

PERIODIC

77-1264

On the Internal Resonance in a Nonlinear Two-Degree-of-Freedom System (Forced Vibrations Near the Lower Resonance Point when the Natural Frequencies are in the Ratio 1:2)

T. Yamamoto and K. Yasuda
Nagoya Univ., Chikusa-ku, Nagoya, Bull. JSME, 20 (140), pp 168-175 (Feb 1977) 10 figs, 3 refs

Key Words: Internal resonance, Forced vibration, Multi-degree-of-freedom systems

A typical case of a two-degree-of-freedom system with internal resonance with a higher natural frequency twice the lower natural frequency, having nonlinear spring characteristic of second and third order polynomials of the displacements is studied. Steady forced vibrations are investigated in the vicinity of the lower resonance point of the system.

RANDOM

(Also see No. 1396)

77-1265

Forced Vibrations of a Mass Connected to an Elastic Half-Space by an Elastic Rod or a Spring

H. Saito and H. Wada
Dept. of Mech. Engrg., Tohoku Univ., Sendai, Japan, J. Sound Vib., 50 (4), pp 519-532 (Feb 22, 1977) 8 figs, 12 refs

Key Words: Forced vibration, Mass half-space systems, Mass spring systems

An analysis of the forced vibrations of a rigid mass connected to an elastic half-space by an elastic rod or a spring and subjected to a harmonic disturbing force in the direction of the rod or the spring axis is presented. The response curves of a rigid mass are obtained, for both uniform normal stress distribution and uniform normal displacement at the interface between a rod and a half-space. Numerical results are presented for three kinds of rod and half-space material combinations, and the effect of stiffness, mass, and damping of an elastic half-space on the response curves of the system are shown. The force transmissibiltiy curves are also given.

77-1266

Solution Bounds for Transient Vibration Problems

T.J. McDaniel, F.J. Testa, and P.V.T. Babu

Dept. of Aerospace Engrg., Iowa State Univ., Ames, IA, J. Appl. Mech. Trans. ASME, 99 (1), pp 159-164 (Mar 1977) 7 refs

Sponsored by NSF

Key Words: Boundary value problems, Transient vibration

The theory of differential inequalities is applied to systems of nonlinear differential equations of the initial value type. Established bounding theorems are used to construct bounds on the solution of these equations and to develop an iterative procedure for improving these bounds. The methods are illustrated by constructing upper and lower solution bounds for one and two-degree-of-freedom dynamic systems.

SEISMIC

(Also see Nos. 1246, 1249, 1311, 1347, 1359, 1360)

77-1267

Shear Wave Velocities from Down-Hole Measurements

H.E. Beeston and T.V. McEvilly

Engrg. Geology Branch, Div. of Struct., Dept. of Transportation, State of California, Sacramento, CA Earthquake Engineering and Structural Dynamics, 5 (2), pp 181-190 (Apr-June 1977) 6 figs, 2 tables, 2 refs

Key Words: Secondary waves, Seismic waves, Wave propagation, Soils, Earthquake response

Shear wave velocities of soils, which provide shear moduli for earthquake response calculations, can be measured clearly and accurately using the down-hole method. Such a method has been used at a number of sites in California with good results to depths of 200 ft. Seismic waves from hammer blows, delivered to the ends of a heavy plank loaded by the front wheels of a vehicle, are received by a three-component geophone in a carefully prepared vertical hole and recorded at 1 mm/ms with a six-channel seismograph. A series of records are obtained at various measured depths in the hole, allowing calculation of interval velocities.

77-1268

Sensitivity Analysis for Hysteretic Dynamic Systems: Theory and Applications

D. Ray, K.S. Pister, and E. Polak

Earthquake Engrg. Res. Ctr., California Univ., Berkeley, CA, Rept. No. EERC-76-12, 62 pp (Feb 1976) PB-262 859/2GA

Key Words: Seismic design, Earthquake resistant structures, Hysteretic damping

Sensitivity analysis, calculation of the rate of change of response variables with respect to design variables, is a critical component in the process of re-analysis for improvement of trial designs or in seeking an optimum design. This report presents necessary theorems and provides details for numerical computation of sensitivity matrices for spatially discretized structural systems subjected to dynamic excitation. General results are presented for nonlinear (hysteretic) structures and explicit numerical examples illustrate the methodology applied to multi-story shear frames whose force-displacement relationship is bilinear hysteretic.

77-1269

Seismic Testing of Reinforced Earth Walls

G.N. Richardson, D. Feger, A. Fong, and K.L. Lee

Dept. of Civil Engrg., N. Carolina State Univ., Raleigh, NC, ASCE J. Geotech. Engr. Div., 103 (1), pp 1-17 (Jan 1977) 11 figs, 6 refs

Key Words: Seismic design, Walls

This paper is a summary progress report of ongoing studies at UCLA toward developing a rational seismic design method for reinforced earth retaining walls. A 20-foot (6-m) high reinforced earth test wall was constructed and then subjected to low strain level forced vibration tests using mechanical vibrators and high strain level explosive tests. In addition, four existing reinforced earth walls were also subjected to forced vibration tests. Criteria are presented for determining the design modal frequencies of a reinforced earth wall needed for the design as a function of its effective height and level of seismic excitation. Data are also presented showing the static and dynamic tie force distribution.

SHOCK

(See Nos. 1250, 1251,1254, 1255, 1285, 1348, 1366, 1367, 1368, 1369, 1382, 1387, 1388, 1389, 1390, 1391, 1392)

PHENOMENOLOGY

COMPOSITE

77-1270

Flutter of Flat Rectangular Anisotropic Plates in High Mach Number Supersonic Flow

R.L. Ramkumar and T.A. Weisshaar
Debt. of Engrg. Science and Mechanics, Virginia Polytechnic Inst. and State Univ., Blacksburg, VA 24061, J. Jound Vib., 50 (4), pp 587-597 (Feb 22, 1977) 6 figs, 16 refs

Key Words: Composite materials, Panels, Flutter

This paper presents the results of a theoretical study of the supersonic flutter of panels composed of advanced composite materials. Three different materials were selected for this study: boron-epoxy, graphite-epoxy, and boron-aluminum. Primary emphasis is given to panels composed of a single layer or ply of material; however, in two instances, the stability behavior of these single layer panels is contrasted with the behavior of panels composed of several layers of material.

DAMPING

77-1271

A Theorem on the Free Vibration of Damped Systems

I. Fawzy
Dept. of Mech. Design, Faculty of Engrg., Univ. of Cairo, Egypt, J. Appl. Mech., Trans. ASME, 99 (1), pp 132-134 (Mar 1977) 6 refs

Key Words: Damped structures, Free vibration

A damped linear system may oscillate freely (with a decaying motion) in "modes". Certain sufficient conditions have been found under which those modes are the principal modes defined in the absence of damping. A simple condition is established in this paper that is both necessary and sufficient for this to be the case. It admits other, hitherto undisclosed, conditions under which this great simplificaiton can validly be adopted.

ELASTIC

77-1272

A Mixed Method in Elasticity

N.S.V.K. Rao and Y.C. Das
Dept. of Civil Engrg., Indian Inst. of Tech., Kanpur-208016, India, J. Appl. Mech., Trans. ASME, 99 (1), pp 51-56 (Mar 1977) 4 figs, 8 refs

Key Words: Elasticity theory, Plates, Forced vibration, Free vibration

A mixed method for three-dimensional elasto-dynamic problems has been formulated which gives a complete choice in prescribing the boundary conditions in terms of either stresses, or displacements, or partly stresses and partly displacements. The general expressions for the responses of the elastic body have been derived in the form of transcendental partial differential equations of a set of initial functions, which can be evaluated in terms of the prescribed boundary conditions. The method so-formulated has been illustrated by applying it to the theory of plates. Only plates subjected to antisymmetric loads have been considered for illustration. Some examples of free and forced vibration of plates have been presented. Results are compared with solutions from existing theories.

FLUID

(Also see Nos. 1296, 1297, 1298, 1315, 1319, 1334, 1335)

77-1273

Pulse Propagation in Fluid-Filled Tubes

J.S. Walker and J.W. Phillips
Dept. of Theoretical and Applied Mechanics, Univ. of Illinois at Urbana-Champaign, Urbana, IL, J. Appl. Mech., Trans. ASME, 99 (1), pp 31-35 (Mar 1977) 6 figs, 6 refs
Sponsored by Argonne National Lab. and NSF

Key Words: Pulse excitation, Fluid-filled containers, Tubes, Sound waves

A new theory for the propagation of pressure pulses in an inviscid compressible fluid contained in a thin-walled elastic tube is presented. This theory represents an improvement over the classical waterhammer theory because the restriction

that the speed of sound in the tube material must be much greater than that in the fluid has been removed and because the restriction that the pulse length must be much greater than the tube diameter has been somewhat relaxed. The new theory is applied to a water-filled copper tube with an axial impulsive force of very short duration applied either to a piston inserted in the anchored end of the tube or to a cap on the free end of the tube. Numerical solutions using the method of characteristics are presented, and comparison is made with the predictions of classical waterhammer theory. A check on the numerical solution is provided by the analytical solution for the capped tube and for the special case when the speed of sound in the tube material and in the fluid are equal.

77-1274

Spatial Resonance of a Liquid-Filled Vibrating Beaker

I. Huntley
Dept. of Mathematics and Computing, Paisley College of Tech., Renfrewshire PA1 2BE, UK, J. Fluid Mech., 80 (1), pp 81-97 (Apr 4, 1977) 3 figs, 1 table, 7 refs

Key Words: Fluid-filled containers, Fluid-induced excitation, Resonant frequency

Mahony & Smith put forward a model to explain the phenomenon of energy transfer between nearly resonant oscillations at greatly differing frequencies. However, their model of 'spatial resonance' is restricted to situations where the geometry of the system is very simple. This paper shows how to derive Mahony & Smith's equations in a general manner, and compares the theoretical predictions for a situation with circular symmetry with existing experimental results (Huntley 1972). In addition, it suggests a simple method for evaluating the resonance frequencies when a liquid-filled beaker is vibrated in one of its bell modes.

SOIL

77-1275

Antiplane Dynamic Soil-Bridge Interaction for Incident Plane SH-Waves

A.M. Abdel-Ghaffar and M.D. Trifunac
Dept. of Civil Engrg., Calif. Inst. of Tech., Pasadena, CA, Earthquake Engineering and Structural Dynamics, 5, pp 107-129 (Apr-June 1977) 13 figs, 1 table, 10 refs

Key Words: Interaction: soil-structure, Secondary waves, Bridges

The analysis of dynamic soil-bridge interaction has been performed in three steps including the analysis of input motions, the force-displacement relationships for the foundations, and the dynamic analysis of the structure itself, i.e. the bridge. Based on the exact solution of the first two steps, the dynamic interaction of a simple two-dimensional bridge model erected on an elastic half-space has been investigated for a single span case. The two-dimensional model under study consists of an elastic shear girder bridge supported by two rigid abutments and rigid foundations which have a circular cross-section and are welded to the half-space.

VISCOELASTIC

77-1276

An Alternative Representation of the Elastic-Viscoelastic Correspondence Principle for Harmonic Oscillations

G. Dasgupta and J.L. Sackman
Div. of Struct. Engrg. and Struct. Mechanics, Univ. of Calif., Berkeley, CA, J. Appl. Mech., Trans. ASME, 99 (1), pp 57-60 (Mar 1977) 1 fig, 5 refs

Key Words: Correspondence principle, Frequency response, Periodic response, Viscoelastic properties, Elastic properties

An alternative representation of the elastic-viscoelastic correspondence principle is derived for solids with identical damping characteristics in bulk and shear undergoing steady-state harmonic motion. This form is particularly useful when the elastic solution of the mechanical system is not available in closed form but is known only numerically.

EXPERIMENTATION

DIAGNOSTICS

(Also see No. 1383)

77-1277
The Determination of Thermal Fluid Flow Engine Blade Damage from Sound Radiation (Untersuchungen zum Erkennen von Schaufelschäden an thermischen Strömungsmaschinen aus der Schallabstrahlung)
R. Freidrich, D. Barschdorff, W. Hensle, and B. Stühlen
Universität Karlsruhe, Karlsruhe, Germany, MTZ Motortech. Z., 38 (3), pp 93-97 (March 1977) 13 figs, 15 refs
(In German)

Key Words: Diagnostic techniques, Turbine blades

Damages of the blading of turbomachines cause shutdowns of long duration as well as high repair cost. The recognition of blade failure is improved by analyzing turbine noise and vibrations. For this purpose, pressure transducers and accelerometers for the measurement, real-time analyzer, and minicomputer for an adopted analysis are used.

77-1278
Acoustical Signature Analysis of High Pressure Fluid Pumping Phenomena
G.E. Maroney
Ph.D. Thesis, Oklahoma State Univ., 299 pp, 1976
UM 77-5138

Key Words: Acoustic signatures, Diagnostic techniques, Pumps

This study examines the proposition that acoustical signature analysis provides a non-intrusive diagnostic technique for high-pressure fluid power systems. The study, which focuses on the acoustical behavior of high pressure gear pumps, considers the theoretical sensitivity of gear pump noise levels to fourteen variables, and experimentally examines the sensitivity of pump noise levels to time (including wear), inlet pressure, outlet pressure, speed, temperature, air/liquid volume ratio, and contamination levels. The theoretical considerations include an acoustical model for pump noise generation, a Noise Wear Index relating acoustical signature variations to component performance degradation, and the definition and discussion of three categories of cavitation.

77-1279
Preventive Maintenance Through Engine Analyzing
W.J. McElroy
Panhandle Eastern Pipe Line Co., Diesel and Gas Turbine Progress, 18 (4), pp 10-11 (Apr 1977)

Key Words: Diagnostic techniques, Compressors, Diagnostic instrumentation

A procedure for analyzing skid-mounted engine compressor units, used in the gas gathering service range from 55 to 2000 hp, is described. If a malfunction is noted, the spark plug or the fuel injection vlave is removed and the cylinder parts and/or valves are visually inspected with the boroscope. The instrument is described in some detail.

77-1280
Designing a Surveillance System
J.S. Mitchell
ENDEVCO, San Juan Capistrano, CA 92675, Power, 121 (3), pp 46-50 (Mar 1977) 10 figs

Key Words: Diagnostic techniques, Rotating structures

The use of dynamic vibration and other operating variables to continuously monitor the health of rotating equipment on-line is described. This article, the first of a four-part series, discusses the types of protection systems needed to guard against unexpected failures.

77-1281
Vibration Analysis by Double Pulsed Laser Holography
A. Felske and A. Happe
Res. and Dev. Div., Volkswagenwerk AG, Germany, SAE Paper No. 770030, 20 pp, 25 figs, 12 refs

Key Words: Internal combustion engines, Engine vibration, Vibration measurement, Diagnostic techniques, Holographic techniques

The use of a giant pulse laser with 30 ns double pulses makes it possible to holograph different phases of an object vibration within time intervals from 100/us to 1 ms onto the same plate. The method of measurement and a hologram camera especially constructed for making double pulsed holograms of automobiles are described. Several examples of application are quoted in order to illustrate this technique.

77-1282
Hidden Cause of Bearing Failure
J.W. Kannel and D.K. Snediker
Battelle Columbus Labs, Columbus, OH, Mach. Des., 49 (8), pp 78-82 (Apr 7, 1977) figs, tables

Key Words: Bearings, Diagnostic techniques

Bearing elements sometimes "rattle" in their cage, producing destructive forces that quickly lead to failure. This phenomenon -- called cage instability -- takes place in a blur of motion that masks the true source of trouble. A method that pinpoints potentially unstable cages at the design stage is described.

77-1283
Special Treatments of Vibration Sources to Reduce Plant Noise. Part 2
L.W. Todd
Noise Control, Vib. and Insul., 8 (3), pp 79-82 (Mar 1977) 5 figs

Key Words: Machinery noise, Noise reduction, Vibration control

This paper has discussed various techniques for reducing machinery noise by reducing or controlling vibration. The methods presented included the detection, analysis and correction of mechanical faults such as unbalance, misalignment and looseness; the control of normal or inherent vibration resulting in radiated noise; and the control of structure-borne vibration.

EQUIPMENT

77-1284
Test Rig for the Automatic Analysis of Friction and Wear in Journal Bearings under Unlubricated Friction Conditions
P. Fornallaz, J. Gehrig, and G. Régnault
Federal Inst. of Tech., Zürich, Switzerland, Wear, 41 (1), pp 63-69 (Jan 1977) 8 figs

Key Words: Journal bearings, Test equipment, Automated testing, Vibration tests

A study is reported of the friction and wear behavior of precision engineering journal bearings for fine mechanisms used in measuring instruments, information transducers and small machinery in order to enable the designer to predetermine their performance. Journal bearings are tested under conditions similar to normal working conditions. Five different measurements, average friction force, variation of friction force (frequency, amplitudes and the probability function of stick-slip vibration), temperature of the shaft surface and wear in two directions, are automatically registered in short intervals. A computer system performs the tasks of process control, data registration, data analysis and data output for a total of 12 test rigs.

FACILITIES

(Also see No. 1347)

77-1285
Fast-Acting Valves for Use in Shock Tubes (Part 1. Construction and their Characteristics)
T. Ikui, K. Matsuo, and Y. Yamamoto
Dept. of Engrg., Kyushu Univ., Fukuoka, Japan, Bull. JSME, 20 (141), pp 337-342 (Mar 1977) 11 figs, 1 table, 7 refs

Key Words: Valves, Shock tubes

Two kinds of fast acting valves developed to replace diaphragm-breaking which is usually employed in the conventional shock tubes are described.

INSTRUMENTATION

77-1286
S/V Sound and Vibration, 11 (3) (March 1977)

Key Words: Measuring instruments

This entire issue is devoted to the instrumentation for dynamic measurement. It contains a comprehensive review of instrumentation hardware including functional descriptions, operational characteristics, typical applications, and examples of typical hardware. Basic measurement techniques, transducers, meters, analyzers, recorders, calibrators, and special systems are covered. Among instruments discussed at length are microphones, accelerometers and other motion transducers, sound-level meters, noise dosimeters, spectrum analyzers, amplitude distribution analyzers, recorders, field calibrators, and special equipment for acoustical measurements.

TECHNIQUES

(Also see Nos. 1262, 1281, 1345, 1412, 1413)

77-1287

State of Art of Modal Survey Test Techniques

N. Niedbal
Deutsche Forschungs- und Versuchsansanstalt für Luft- und Raumfahrt, Goettingen, W. Germany,
In: ESA Modal Survey, pp 13-24 (1976) (N77-16379) N77-16382

Key Words: Modal tests, Testing techniques

Beside the classical phase resonance method, some new modal survey test techniques are described (Angelini's, Natke's, Wittmeyer's methods) and some tests were compared to demonstrate the necessity to check the new modal survey test methods systematically. A structure was simulated by a mathematical model with three degrees of freedom.

COMPONENTS

SHAFTS

77-1288

The Effect of External Damping on the Vibration of Flexible Shafts Supported on Oil-Film Bearings

M. Dostal, J.B. Roberts, and R. Holmes
School of Engrg. and Applied Sciences, Univ. of Sussex, Brighton BN1 9QT, UK,
J. Sound Vib., 51 (1), pp 69-87 (Mar 8, 1977) 17 figs, 11 refs

Sponsored by Ministry of Defense (Ships Dept.), Science Res. Council

Key Words: Rotor-bearing systems, Shafts, Fluid-film bearings, External damping, Damping effects

This paper discusses the use of intermediate, externally applied damping as a means of controlling the synchronous response of a flexible shaft supported on oil-film bearings. A method of finding the optimum magnitude of the external damper, and its optimum position, is described, which exploits the existence of "fixed points" on the amplitude-frequency response curves. The theoretical conclusions are supported by experimental results obtained from a uniform shaft carried on two oil-film bearings.

77-1289

On the Transition of a Shaft Through Critical Speeds

B.M. Naveh and R.M. Brach
Dept. of Aerospace and Mech. Engrg., Univ. of Notre Dame, Notre Dame, IN,
J. Dyn, Syst., Meas. and Control, Trans. ASME, 99 (1), pp 48-50 (Mar 1977) 4 figs, 4 refs

Key Words: Shafts, Critical speeds

The motion of an eccentric rotating shaft and disk is studied for an exponential transition of the angular velocity (spin rate) through a critical speed. An analytical solution is found for the response, and it is shown that this response can yield higher amplitudes when compared to previous work where the angular velocity is varied linearly.

BEAMS, STRINGS, RODS

(Also see Nos. 1236, 1241, 1326)

77-1290

Mechanical Four-Pole Parameters: Transmission Matrices

J.C. Snowdon
Applied Res. Lab., Pennsylvania State Univ., University Park, PA,
Rept. No. TM-76-122, 92 pp (Apr 19, 1976)
AD-A034 442/4GA

Key Words: Beams, Flexural vibrations, Matrix methods

This report revises and extends an earlier report entitled 'Mechanical Four-Pole Parameters and their Application' (Journal of Sound and Vibration, 15, 307-323, 1971). Newly considered are so-called transmission matrices, which enable the transverse vibration response of beams with discontinuities to be analyzed readily. Further, the transmission matrices used in the report result in more concise beam analyses than the matrices generally employed in the literature. Additional examples that are considered here include end-driven cantilever beams or stanchions that are propped by a damped spring; or that carry an end mass having a finite moment of inertia; or that carry a mass that divides the stanchion into two stages of arbitrary lengths and cross-sectional areas; or that carry an end mass and subsequently comprise three stages having arbitrary lengths and cross-sectional areas.

77-1291

Coupled Bending and Twisting of a Timoshenko Beam

R.E.D. Bishop and W.G. Price
Dept. of Mech. Engrg., Univ. College London, London WC1E 7JE, UK, J. Sound Vib., 50 (4), pp 469-477 (Feb 22, 1977) 3 refs

Key Words: Beams, Timoshenko theory, Coupled response, Transverse shear deformation effects, Rotatory inertia effects, Ship hulls

Allowance is made for shear deflection and for rotary inertia of a non-uniform beam that executes coupled bending and twisting vibration. Principal modes are found, orthogonality conditions established and modal equations of forced motion derived.

77-1292

The Second Frequency Spectrum of Timoshenko Beams

B.A.H. Abbas and J. Thomas
Dept. of Mech. Engrg., Univ. of Surrey, Guildford GU2 5XH, UK, J. Sound Vib., 51 (1), pp 123-137 (Mar 8, 1977) 13 figs, 12 refs

Key Words: Beams, Timoshenko theory, Coupled response, Transverse shear deformation effects, Rotatory inertia effects

This paper investigates the reported existence of a second spectrum of frequencies of vibration of Timoshenko beams. A concept of coupled vibration is introduced and is used to explain the behavior of the Timoshenko beams with various end conditions.

77-1293

An Experimental-Theoretical Correlation Study of Non-Linear Bending and Torsion Deformations of a Cantilever Beam

E.H. Dowell, J. Traybar, and D.H. Hodges
Dept. of Aerospace and Mech. Sciences, Princeton Univ., Princeton, NJ 08540, J. Sound Vib., 50 (4), pp 533-544 (Feb 22, 1977) 9 figs, 10 refs

Key Words: Cantilever beams, Flexural vibrations, Natural frequencies

An experimental study of the large deformation of a cantilevered beam under a gravity tip load has been made. The beam root is rotated so that the tip load is oriented at various angles with respect to the beam principal axes. Static twist and bending deflections of the tip and bending natural frequencies have been measured as a function of tip load magnitude and orientation. The experimental data are compared with the results of a recently developed non-linear structural theory. Agreement is reasonably good when bending deflections are small compared to the beam span, but systematic differences occur for larger deflections.

77-1294

The Transverse Vibration of a Doubly Tapered Beam

D.O. Banks and G.J. Kurowski
Dept. of Math., Univ. of Calif., Davis, CA 95616, J. Appl. Mech., Trans. ASME, 99 (1), pp 123-126 (Mar 1977) 1 fig, 4 refs

Key Words: Beams, Variable cross section, Flexural vibrations

The transverse vibrations of a thin homogeneous beam which is symmetric with respect to the x-y and x-z planes is analyzed.

77-1295

Shear and Bending Response of a Rigid-Plastic Beam to Blast-Type Loading

T. Nonaka
Disaster Prevention Res. Inst., Kyoto Univ., Uji City, Kyoto Prefecture, Japan, Ing. Arch., 46, pp 35-52 (1977) 17 figs, 17 refs

Key Words: Beams, Dynamic response, Blast response

An analysis is presented of the dynamic behavior and permanent deformation of a rigid-perfectly plastic beam subjected to blast-type loading. The beam is simply supported at the ends, and the load is uniformly distributed over the span. The analysis is based on an approximate yield curve relating limiting values of shear force and bending moment.

77-1296

A New Look at Decomposition of Turbulence Forcing Field and the Structural Response

Y.K. Lin and S. Maekawa
Dept. of Aeron. and Astron. Engrg., Univ. of Illinois, Urbana-Champaign, IL, Rept. No. NASA-CR-149511, 22 pp (Mar 22, 1976) 4 figs, refs (Backup document for AIAA Synoptic, "Decomposition of Turbulence Forcing Field and Structural Response," scheduled for publication in AIAA Journal in May 1977) N77-15988

Key Words: Beams, Interaction: structure-fluid

Measured cross-spectrum of a turbulence field usually shows some decay in the statistical correlation in addition to convection at a characteristic velocity. In this paper it is shown that a decaying turbulence can be decomposed into frozen-pattern components thus permitting a simpler way to calculate the structural response. This procedure also provides a relationship whereby the measured input spectra can be incorporated. The theory is applied to an infinite beam which is backed on one side by a fluid filled cavity and is exposed on the other side by the turbulence excitation. The effect of the free stream velocity is also taken into consideration.

77-1297

On Some Structure-Turbulence Interaction Problems

S. Maekawa and Y.K. Lin

Dept. of Aeron. and Astron. Engrg., Univ. of Illinois, Urbana-Champaign, IL, Rept. No. NASA-CR-149461, 116 pp (Dec 1976) 6 figs, refs

N77-15986

Key Words: Interaction: structure-fluid, Beams, Aircraft

The interactions between a turbulent flow structure responding to its excitation were studied. The turbulence was typical of those associated with a boundary layer, having a cross-spectral density indicative of convection and statistical decay. A number of structural models were considered. Among the one-dimensional models were an unsupported infinite beam and a periodically supported infinite beam. The fuselage construction of an aircraft was then considered.

77-1298

Dynamic Response of Some Tentative Compliant Wall Structures to Convected Turbulence Fields

H.H. Nijim and Y.K. Lin

Dept. of Aeron. and Astron. Engrg., Univ. of Illinois, Urbana-Champaign, IL, Rept. No. NASA-CR-149462, 119 pp (Dec 1976) 24 figs, 5 tables, refs

N77-15985

Key Words: Beams, Viscoelastic foundations, Membranes, Turbulence, Interaction: structure-fluid

Compliant wall structures designed for possible skin friction drag reduction were investigated. A ribbed membrane backed by polyurethane or PVS plastisol was among the structural models considered. This model was simplified as a beam placed on a viscoelastic foundation and on a set of evenly spaced supports. The total length of the beam was either finite or infinite, and the supports were either rigid or elastic. Another structural model considered was a membrane mounted over a series of pre-tensioned wires, also evenly spaced, with the entire membrane backed by an air cavity.

77-1299

Influence of Shearing Deformation and Rotatory Inertia on the Lateral Vibration of a Beam with Nonuniform Cross Section and a Disc with Axisymmetric Nonuniform Thickness Distribution. II

T. Sekiguchi and H. Takeyama

Dept. of Engrg., Tohoku Univ., Sendai, Japan, Tech. Rept., 41 (2), pp 251-265 (1976) 8 figs, 3 refs

Key Words: Beams, Variable cross section, Natural frequencies, Lateral response, Transverse shear deformation effects, Rotatory inertia effects

Natural frequencies of bending vibration of simple frames accompanied with longitudinal vibration under the action of the gravitational force are given. Iteration with a functional, derived from the vibration equations in which the effect of rotary inertia and shearing deformation is considered, was performed.

77-1300

Dynamic Interactions Between Vehicles and Elevated, Flexible Randomly Irregular Guideways

J.E. Snyder, III and D.N. Wormley

Dept. of Mech. Engrg., Massachusetts Inst. of Tech., Cambridge, MA, J. Dyn. Syst., Meas. and Control, Trans. ASME, 99 (1), pp 23-33 (Mar 1977) 10 figs, 23 refs

Key Words: Overhead guideways, Moving loads, Beams, Bernoulli-Euler method, Modal analysis

A dynamic interaction model is formulated for the heave-pitch motion of vehicles crossing elevated flexible, randomly irregular spans. Span dynamic motion due to a vehicle passage is modeled using a Bernoulli-Euler beam model and modal analysis techniques. Four types of random irregularities characteristic of elevated guideways are modeled numerically including vertical span offset, pier misalignment, camber, and surface roughness. Analytical expressions for each irregularity power spectral density are derived and the relative contributions of irregularities to vehicle excitation are examined. The limitations to vehicle passenger comfort levels posed by guideway deflection and irregularity are illustrated for personal and rapid transit types of vehicles.

77-1301
Natural Frequencies of Timoshenko Beams on Pasternak Foundations
T.M. Wang and J.E. Stephens
Dept. of Civil Engrg., Univ. of New Hampshire, Durham, NH 03824, J. Sound Vib., 51 (2), pp 149-155 (Mar 22, 1977) 1 fig, 14 refs

Key Words: Natural frequencies, Beams, Timoshenko theory, Pasternak foundations

A study of the natural vibrations of a Timoshenko beam on a Pasternak-type foundation is presented. Frequency equations are derived for beams with different end restraints. A specific example is given to show the effects of rotary inertia, shear deformation, and foundation constants on the natural frequencies of the beam.

77-1302
Torsional Vibrations of a Sapphire Rod: A Numerical Description
L.O. Wilson and M. Gatto
Bell Labs., Murray Hill, NJ 07974, J. Acoust. Soc. Amer., 61 (4), pp 1004-1013 (Apr 1977) 10 figs, 5 refs

Key Words: Rods, Torsional vibration, Fibers

A numerical description of the lowest-order torsional mode of vibration of a c-axis sapphire rod is obtained from two approximate theories. One theory involves an *infinite-series* perturbation expansion about an expression which describes modes along a transversely isotropic rod. The other theory involves a low-frequency asymptotic expansion for the lowest-order torsional mode of sapphire. At frequencies for which both theories are expected to be valid, there is excellent numerical agreement.

77-1303
Waves in Elastic Rods
H. Cohen and A.B. Whitman
Dept. of Civil Engrg., Univ. of Manitoba, Winnipeg, Manitoba, Canada, J. Sound Vib., 51 (2), pp 283-302 (Mar 22, 1977) 2 figs, 17 refs
Sponsored by the National Science Foundation, the National Research Council of Canada, and the Univ. of Manitoba Res. Board

Key Words: Rods, Shock waves, Wave propagation

The problem of shock wave propagation within the framework of a linear director theory of elastic rods is examined for the case of uniform and non-uniform rods. Particular attention is paid in this study to the effect of rod curvature and twist on the wave speeds, wave modes and induced waves.

77-1304
Axial Impact of Twisted Wire Cables
J.W. Phillips and G.A. Costello
Dept. of Theoretical and Applied Mechanics, Univ. of Illinois, Urbana-Chambaign, IL, J. Appl. Mech., Trans. ASME, 99 (1), pp 127-131 (Mar 1977) 6 figs, 18 refs

Key Words: Cables (ropes), Wire, Axial excitation

The nonlinear, coupled equations of motion governing the axial and rotational displacements of a straight, single lay, twisted wire cable are presented. Linearization of the equations of motion allows a solution by Laplace transforms which is valid for arbitrary initial and boundary conditions. The longitudinal impact of a finite-length cable fixed at one end is considered in detail, and numerical results for this case are presented.

BEARINGS

(Also see Nos. 1282, 1284)

77-1305
Analysis of Vibrations Produced by an Operating Ball Bearing (Analyse Des Vibrations Generees Par Un Roulement a Billes en Fonctionnement)
Mommessin
Laboratoire de Recherches Balistiques et Aerodynamiques, Vernon, France, Rept. No. LRBA-E-602-NT50/SIE, 23 pp (Apr 8, 1976)
(In French)
N77-16343

Key Words: Ball bearings, Vibration response

Vibrations produced by the operation of a ball bearing with oblique contact, and limited to frequencies generated by the rolling kinematics and by the free vibration of its elements, were determined theoretically. The investigation concerned a ball bearing with fixed internal ring/moving external ring. Results of numerical applications concerning miniature highspeed bearings of dimensions R 1.5 and R 3 revolving at 400 rps are presented. This allows identification of all frequencies occurring in a vibration spectrum between 0 and 2,000 Hz.

77-1306

Dynamic Behavior of a 140,000 rpm 3 kw Turbo-Alternator Simulator on Resiliently Mounted Ball Bearings

L.W. Winn and F.D. Jordan

Applied Tribology Section, Mechanical Technology, Inc., Latham, NY, SAE Paper No. 770282, 24 pp, 22 figs, 3 refs

Key Words: Rotor-bearing systems, Ball bearings, Flexible foundations

This paper represents the results of rotor dynamic and limited endurance tests performed on resiliently mounted 10 mm bore ball bearings supporting a test vehicle designed to dynamically simulate a 3 kw Turbo-alternator rotor operating at 140,000 rpm. Squirrel cage and "O" ring type bearing supports were employed in two separate tests. The accumulated total test time was 4,500 hours.

77-1307

Variational Method for Finite Length Squeeze Film Damper Dynamics with Applications

P.E. Allaire, L.E. Barrett, and E.J. Gunter

Dept. of Mech. Engrg., Univ. of Virginia, Charlottesville, VA 22901, Wear, 42, pp 9-22 (1977) 9 figs, 11 refs

Key Words: Squeeze-film bearings, Stiffness coefficients, Damping coefficients, Variational methods

A variational method of solving Reynold's equation and of determining the load capacity analytically is obtained for the finite length squeeze film damper undergoing full dynamic motion. The method is then used to determine effective damper coefficients for circular synchronous precession and a non-linear transient analysis is carried out for several damper configurations.

BLADES

(Also see No. 1277)

77-1308

Three-Dimensional Analysis of Blade Force and Sound Generation for an Annular Cascade in Distorted Flows

M. Namba

Dept. of Aeron. Engrg., Kyushu Univ., Hakozaki, Higashi-ku, Fukuoka 812, Japan, J. Sound Vib., 50 (4), pp 479-508 (Feb 22, 1977) 19 figs, 6 refs

Key Words: Blades, Sound generation

An unsteady lifting-surface theory for a rotating subsonic annular cascade has been developed to predict the unsteady blade forces and the acoustic power generation caused by interaction of blades with inlet distortions or wakes. Disturbance pressure and velocity fields induced by the rotor blades with fluctuating blade force are expressed in terms of the blade force distribution and kernel functions. The spanwise distribution of the blade force is given as a sum of blade force modes, and the kernel functions are resolved into the corresponding modal components. Numerical computations have been conducted for interaction with the external disturbance flows that are sinusoidal in the circumferential direction, but possess a phase skewing in the radial direction. Correlations among the acoustic modes, the blade force modes and the flow patterns of the external disturbance have been investigated.

77-1309

Free Vibration of Blade Packets

J. Thomas and H.T. Belek

Dept. of Mech. Engrg., Univ. of Surrey, Guildford GU2 5XH, UK, J. Mech. Engr. Sci., 19 (1), pp 13-21 (1977) 11 figs, 14 refs

Key Words: Turbine blades, Shrouds, Free vibration, Finite element technique

The free-vibration characteristics of shrouded blade packets are studied using the finite-element method. The effects of various weight ratios, flexural rigidity ratios and length ratios between the blades and shrouds on the frequencies of vibration of the blade packet are investigated.

77-1310

Rotor Blade Flapping Criteria Investigation

L.W. Dooley

Bell Helicopter Textron, Fort Worth, TX 76100, Rept. No. 699-099-021, USAAMRDL-TR-76-33, 100 pp (Dec 1976)
AD-A034 459/8GA

Key Words: Rotary wings, Helicopter rotors, Flutter

The objective of this study was to identify helicopter characteristics critical to main rotor flapping and to attempt to establish flapping design criteria. Three helicopter types and three rotor systems were simulated in steady flight and maneuvers using the hybrid version of C81, Rotor craft flight Simulation Program.

COLUMNS

77-1311

Design of Column Sections Subjected to Three Components of Earthquake

A.K. Gupta and M.P. Singh

Structural Analytical Div., Sargent and Lundy Engrs., Chicago, IL 60603, Nucl. Engr. Des., 41 (1), pp 129-133 (Mar 1977) 5 figs, 2 refs

Key Words: Columns, Seismic design, Earthquake resistant structures

This paper presents the derivation of a procedure for the seismic design of column sections subjected to combinations of axial force and moments which probalistically can occur simultaneously.

77-1312

Static and Dynamic Behavior of 'Tri-Chord Truss' Overhead Sign Support Structures

J.F. Mirza, C.C. Tung, and J.C. Smith

Highway Res. Program, N. Carolina State Univ., Raleigh, NC, Rept. No. ERSD-110-71-3, FHWA/RD-77-S0560, 321 pp (Sept 1975)

Sponsored by N. Carolina Dept. of Transportation and Highway Safety, Raleigh, NC

PB-262 572/1GA

Key Words: Columns, Trusses, Suspended structures, Wind induced excitation, Vibration damping, Computer programs

This report presents the results of a three part research effort on the experimental, static, and dynamic behavior of tri-chord overhead sign support structures.

CYLINDERS

77-1313

Acoustically Induced Vibration of Circular Cylindrical Rods

H.-C Lin and S.-S. Chen

Components Tech. Div., Argonne National Lab., Argonne, IL 60439, J. Sound Vib., 51 (1), pp 89-96 (Mar 8, 1977) 5 figs, 12 refs

Key Words: Cylinders, Rods, Periodic response, Acoustic excitation, Nuclear reactor components

An analysis is presented for the steady-state response of a circular cylindrical rod subjected to a plane wave; expressions for the rod displacement, the natural frequency (including the fluid inertia effect) and the radiation damping are obtained in closed form.

77-1314

An Improved Mathematical Model for the Aerodynamic Forces on Tandem Cylinders in Motion with Aeroelastic Applications

A. Simpson and J.W. Flower

Dept. of Aeron. Engrg., Univ. of Bristol, Bristol BS8 1TR, UK, J. Sound Vib., 51 (2), pp 183-217 (Mar 22, 1977) 11 figs, 2 tables, 21 refs

Key Words: Cylinders, Flutter, Mathematical models

The quasi-steady theory of wake-induced flutter has been vindicated in the literature for the case where the wake-generating body is rigidly fixed. While several studies have attempted to extend the simple theory to the more general case where both windward and leeward bodies are in motion, none has really succeeded in producing a viable mathematical wake model which takes account of the effects of time delays associated with the gap between the bodies. The present paper, it is believed, provides such a model and deals with effects not previously conceived in this area, notably "bunching" of the wake due to accelerated motions of the windward body and "virtual displacement" of the leeward body due to flow retardation in its stagnation region.

77-1315

Hydrodynamic Damping and 'Added Mass' for Flexible Offshore Platforms

C. Petrauskas

Hydraulic Engrg. Lab., Univ. of Calif., Berkeley, CA, Rept. No. HEL-9-23, CERC-TP-76-18, 113 pp (Oct 1976)

AD-A034 534/8GA

Key Words: Cylinders, Offshore structures, Water waves

The dynamic response of deepwater flexible platforms due to wind-generated ocean waves appears to be an important design consideration; therefore, a theoretical and experimental study was made of hydrodynamic damping and 'added mass.'

DUCTS

77-1316

A Finite Element Method for Duct Acoustic Problems

S. Ling

Ph.D. Thesis, Purdue University, Lafayette, IN, 134 pp, 1976

UM 77-7483

Key Words: Ducts, Noise reduction, Finite element technique

In duct acoustics, exact solution is difficult to obtain because of the presence of airflow, soft walls, varying cross sectional area, and the duct terminus radiation load. A Galerkin based finite element method is developed with the intent to solve these difficulties.

77-1317

Sound Propagation in Choked Ducts

A.S. Hersh and C.Y. Liu

Hersh Acoustical Engrg., Chatsworth, CA, Rept. No. NASA-CR-135123, 44 pp (Dec 1976)

N77-15792

Key Words: Ducts, Variable cross section, Sound transmission

The linearized equations describing the propagation of sound in variable area ducts containing flow are shown to be singular when the duct mean flow is sonic.

77-1318

Ducts with Axial Temperature Gradients: An Approximate Solution for Sound Transmission and Generation

A. Cummings

Inst. of Environ. Science and Tech., Polytechnic of the South Bank, London SE1 0AA, UK, J. Sound Vib., 51 (1), pp 55-67 (Mar 8, 1977) 6 figs, 7 refs

Key Words: Ducts, Sound generation, Sound transmission, Wave equation

This paper is concerned with rigid-walled ducts in which axial temperature gradients exist. An acoustic wave equation is derived (an independently specified source distribution is assumed to be present) and its solution is discussed.

77-1319

Flow Oscillations in a Duct with a Rectangular Cross-Section

J.S. Anderson, W.M. Jungowski, W.J. Hiller, and G.E.A. Meier

Dept. of Mech. Engrg., The City Univ., London, UK, J. Fluid Mech., 79 (4), pp 769-784 (Mar 1977) 6 figs, 20 refs

Key Words: Ducts, Fluid-induced excitation

A two-dimensional configuration has been investigated in which air flows through a convergent nozzle and expands abruptly into a rectangular duct of larger cross-section which terminates in a plenum chamber. The unsteady duct phenomena have been studied by synchronizing instantaneous pressures measured by quartz pressure transducers with interferograms obtained with a Mach-Zehnder interferometer.

77-1320

Adjointness Properties for Differential Systems with Eigenvalue-Dependent Boundary Conditions, with Application to Flow-Duct Acoustics

R.E. Kraft and W.R. Wells

Acoustic Treatment Div., Aircraft Engine Group, General Electric Co., Cincinnati, OH 45215, J. Acoust. Soc. Amer., 61 (4), pp 913-922 (Apr 1977) 9 figs, 1 table, 11 refs

Key Words: Ducts, Elastic waves

When the boundary conditions at the two endpoints of a second-order differential system depend explicitly upon the eigenvalues such that the system becomes non-self-adjoint, a generalized condition of orthogonality which includes endpoint terms can be developed. The generalized orthogonality condition is used to determine modal coefficients for the expansion of arbitrary functions in series of eigenfunctions. The method is applied to the particular case of acoustic wave propagation in a rectangular duct with a uniform mean-flow profile and walls with finite acoustic impedance. The ability of the eigenfunction expansion to converge to a plane-wave acoustic pressure profile is demonstrated under a variety of flow, frequency, and wall-impedance conditions.

77-1321

Optimal One-Section and Two-Section Circular Sound-Absorbing Duct Liners for Plane-Wave and Monopole Sources without Flow

H.C. Lester and J.W. Posey

NASA, Langley Res. Ctr., Langley Station, VA,

Rept. No. NASA-TN-D-8348; L-11039, 53 pp (Dec 1976)
N77-15790

Key Words: Ducts, Acoustic linings

A discrete frequency study is made of the influence of source characteristics on the optimal properties of acoustically lined uniform and two section ducts. Two simplified sources, a plane wave and a monopole, are considered in some detail and over a greater frequency range than has been previously studied. Source and termination impedance effects are given limited examination. An example of a turbomachinery source and three associated source variants is also presented.

LINKAGES

77-1322
Metal Diaphragm Coupling Performance
M.M. Calistrat
Koppers Co., Inc., Baltimore, MD, Hydrocarbon Processing, 56 (3), pp 137-144 (Mar 1977) 23 figs, 3 refs

Key Words: Flexible couplings, Testing techniques

Endurance limit is the main factor in determining diaphragm coupling life. This limit can be estimated by calculations but it must be confirmed by testing. The results of such a testing program are given herein.

77-1323
Influence of Shearing Deformation and Rotatory Inertia on the Lateral Vibration of a Beam with Nonuniform Cross Section and a Disc with Axisymmetric Nonuniform Thickness Distribution. III
T. Sekiguchi and H. Takeyama
Dept. of Engrg., Tohoku Univ., Japan, Tech. Rept., 41 (2), pp 267-280 (1976) 9 figs, 4 refs

Key Words: Discs, Variable cross section, Natural frequencies, Lateral response, Transverse shear deformation effects, Rotatory inertia effects

Natural frequencies of bending vibration of discs with some typical thickness distributions along the radius are obtained by considering rotatory inertia and shearing deformation. Iteration with a functional derived from the energetical relations in lateral vibration of the disc is used. The method is applicable to solve problems of vibration of the disc of any axisymmetric thickness varying along the radius in the axisymmetrical condition of plane stress.

MECHANICAL

77-1324
Torsional Vibrations of Pile Foundations
M. Novak and J.F. Howell
Univ. of Western Ontario, London, Canada, ASCE J. Geotech. Engr. Div., 103 (4), pp 271-285 (Apr 1977) 8 figs, 9 refs

Key Words: Pile foundations, Torsional excitation, Interaction: soil foundation

Figures are presented to facilitate the determination of the response of various representative footings to torsional excitation.

MEMBRANES, FILMS, AND WEBS

77-1325
Vibration of a Membrane Having a Circular Outer Boundary and an Eccentric Circular Inner Boundary
K. Nagaya
Faculty of Engrg., Yamagata Univ., Jyonan, Yonezawa, Japan, J. Sound Vib., 50 (4), pp 545-551 (Feb 22, 1977) 2 figs, 12 refs

Key Words: Membranes, Waveguide analysis

A method of solving vibration problems for a membrane having a circular outer boundary and an eccentric circular inner boundary is presented. The frequency equation for the membrane is given, and the dependence of the natural frequency on the eccentricity is obtained.

77-1326
On the Dynamics of Elastic Membranes and Cords as Slender Bodies
A. Galka
Tech. Univ. (Polytechnika Swietokryzka Kielce) Ul. Tysiąclecia Państwa Polskiego 17 25-314 Kielce, Poland, Bull. Acad. Polon. Sci., Ser. Sci. Tech., 24 (10), pp 423-427, 2 refs

Key Words: Membranes, Strings

The derivation of the dynamics of membranes and cords directly from the general equations of mechanics of nonstandard continua is presented. Membranes and cords are defined as three-dimensional bodies with a special form of constraints imposed on the kinetic fields.

PIPES AND TUBES

(Also see Nos. 1273, 1334)

77-1327

Flutter of Articulated Pipes at Finite Amplitude

J. Rousselet and G. Herrmann

Dept. of Applied Mechanics, School of Engrg., Stanford Univ., Stanford, CA, J. Appl. Mech., Trans. ASME, 99 (1), pp 154-158 (Mar 1977) 3 figs, 6 refs

Key Words: Pipes (tubes), Flutter, Fluid-filled containers

The plane motion of an articulated pipe made of two segments is examined and the flow velocity at which flutter manifests itself is sought. A graph of the amplitude of the limit cycles, as a function of the fluid-system mass ratio, is presented and conclusions are drawn as to the necessity of considering nonlinearities in the analysis.

77-1328

An Efficient Simulation Method for Distributed Lumped Fluid Networks

R.S. Sidell and D.N. Wormley

Massachusetts Inst. of Tech., Cambridge, MA, J. Dyn. Syst., Meas. and Control, Trans. ASME, 99 (1), pp 34-40 (Mar 1977) 15 figs, 13 refs

Key Words: Piping systems, Computerized simulation

A method is presented for the simulation of fluid networks consisting of uniform distributed elements and lumped dynamic, nonlinear elements. The uniform transmission elements may suffer from losses and dispersion. General relationships are derived for their terminations in junctions with other elements and/or with dynamic, nonlinear lumped elements. Simulation results are compared with experimental data for a pneumatic transmission line terminated with a nonlinear resistance and for a pneumatic transmission network consisting of three lines of incommensurate lengths.

PLATES AND SHELLS

(Also see No. 1272)

77-1329

Doubly-Curved Variable-Thickness Isoparametric Heterogeneous Finite Element

M.D. Minich and C.C. Chamis

Dept. of Civil Engrg., Cleveland State Univ., Cleveland, OH 44115, Computers and Struc., 7 (2), pp 295-301 (Apr 1977) 7 figs, 6 tables, 12 refs

Key Words: Shells, Finite element technique

This paper describes an element streamlined for the analysis of doubly-curved, variable-thickness structural components and illustrates its effective application to vibration and static problems. The element is isoparametric, doubly-curved, thin-shell and triangular with variable thickness and accounts for anisotropic, inhomogeneous elastic material behavior. The element has six nodes (three corner and three mid-side) with five degrees-of-freedom (DOF) per node -- three translations and two rotations. Quadratic isoparametric interpolation polynomials are used to express the element geometry and displacement variables in terms of corresponding nodal variables.

77-1330

Structural Instability and Natural Vibration Analysis of Thin Arbitrary Shells by Use of the Semiloof Element

R.A.F. Martins and D.R.J. Owen

Univ. College of Swansea, Wales, UK, Intl. J. Numer. Methods Engr., 11 (3), pp 481-498 (Mar 1977 11 figs, 34 refs

Key Words: Shells, Variable cross-section

At present the Semiloof element is probably one of the most efficient available for the solution of thin shells of arbitrary geometry. Experience in static situations indicates that accurate results can be obtained for non-trivial geometric and loading configurations with relatively coarse meshes. Variable thickness shells or discontinuous thicknesses can be accommodated and no difficulties are encountered in modeling sharp corners or multiple junctions in structures. This paper examines the element behavior when applied to elastic instability and vibration situations. An eigenvalue solution scheme based on Sturm sequences is presented which does not require the usual elimination of a percentage of the total nodal variables by static condensation. Finally the method is assessed by the solution of several numerical examples.

77-1331

Transient Response of a Moving Spherical Shell in an Acoustic Medium

N. Akkas

Dept. of Civil Engrg., Middle East Tech. Univ., Ankara, Turkey, Intl. J. Solids Struc., 13 (3), pp 211-220 (1977) 5 figs, 20 refs

Key Words: Transient response, Spherical shells, Fluid-induced excitation

A ring-stiffened spherical shell is submerged in an acoustic medium. The shell is thin and elastic. The acoustic medium is inviscid, irrotational and compressible. The center of mass of the shell is subjected to a translational acceleration which is an arbitrary function of time. The absolute displacements of the shell are expressed in terms of the relative displacements and the displacement of the base of the shell, base being defined as the rigid ring placed at the equator. The transient response of the shell is investigated numerically. The results are compared with the results of the in-vacuo response. The effects of the plane wave approximation and the base velocity on the transient response of the shell are studied.

77-1332

Vibrations of Thin Elastic Shells -- A New Approach

M.J.A. O'Callaghan, W.A. Nash, and P.M. Quinlan
Dept. of Civil Engrg., Massachusetts Univ., Amherst, MA, Rept. No. AFOSR-TR-76-1455, 8 pp (July 1976)
AD-A033 942/4GA

Key Words: Spherical shells, Natural frequencies, Mode shapes, Computer programs

A previous investigation by one of the present authors extended the method of Edge-Functions to the determination of natural frequencies and associated mode shapes of free vibration of thin elastic plates with a variety of boundary conditions. The present investigation further extends this approach to the case of a shallow elastic spherical shell of n-sided polygonal plan-form. Natural frequencies and associated mode shapes together with boundary residuals (indicating how well the approximate solution has satisfied boundary conditions) are readily displayed by the computer program offered.

77-1333

Effect of the Spatial Distribution of Impulsive Loads on Dynamic Snap-Through Stability of a Shallow Cylindrical Shell

E. Johnson
Ph.D. Thesis, The University of Michigan, 199 pp, 1976
UM 77-7949

Key Words: Cylindrical shells, Shallow shells, Arches, Snap-through problem

When a shallow cylindrical shell or arch is subjected to sufficiently large impulsive loads, it will dynamically snap-through into configurations with reserve curvature. Previous investigations have suggested that the initial energy required to cause this is sensitive to the spatial distribution of the loading. This thesis investigates this question in depth.

77-1334

Dynamic Stability of Isotropic or Composite-Material Cylindrical Shells Containing Swirling Fluid Flow

T.L.C. Chen and C.W. Bert
Univ. of Oklahoma, Norman, OK 73069, J. Appl. Mech., Trans. ASME, 99 (1), pp 112-116 (Mar 1977) 5 figs, 16 refs

Key Words: Cylindrical shells, Piping systems, Composite materials, Fluid-filled containers, Fluid-induced excitation

A linear stability analysis is presented for a thin-walled, circular cylindrical shell of orthotropic material conveying a swirling flow. Shell motion is modeled by using the dynamic orthotropic version of the Sanders shell theory and fluid forces are described by inviscid, incompressible flow theory. The critical flow velocities are determined for piping made of composite and isotropic materials conveying swirling water. Fluid rotation strongly degrades the stability of the shell/fluid system, i.e. increasing the fluid rotating speed severely decreases the critical flow velocity.

77-1335

Time Harmonic Acoustic Radiation from a Submerged Elastic Shell Defined by Nonconcentric Cylinders

R.P. Shaw
Dept. of Engrg. Science, Aerospace Engrg. and Nuclear Engrg., State Univ. of New York at Buffalo, NY, Rept. No. 97, 44 pp (Sept 1976)
AD-A034 886/2GA

Key Words: Cylindrical shells, Submerged structures, Elastic waves

The acoustic radiation from an elastic cylindrical shell defined by nonconcentric cylindrical surfaces and submerged in an acoustic fluid is studied. The driving mechanism is a time harmonic internal pressure. In particular, the influence of the nonconcentricity parameter, delta, on the resulting radiation field is examined.

77-1336

Frequency Analysis of Plates Vibrating at Large Amplitudes

J. Ramachandran
Dept. of Mech. Engrg., Technische Hogeschool Twente, Enschede, Holland, J. Sound Vib., 51 (1), pp 1-5 (Mar 8, 1977) 1 fig, 16 refs

Key Words: Plates, Fundamental frequency, Amplitude analysis

A new method of finding the relationship between non-linear fundamental frequency of vibration and the amplitude of vibration of plates is explained in this paper. In this method use is made of an iteration procedure suggested by Schwarz and also of Berger's equations. As an example, a circular plate with clamped, immovable edges is considered.

77-1337
Snubbers Calm PCB Vibration
D.S. Steinberg
Singer Kearfott Div., Wayne, NJ, Mach. Des., 49 (7), pp 71-73 (Mar 24, 1977) 3 figs

Key Words: Circuit boards, Plates, Vibration control

Typical printed-circuit boards, supported only at their edges, often vibrate under dynamic loads. The result can be cracked solder joints, broken leads, and loose components. Limiting destructive vibration with inexpensive rubber snubbers is discussed.

77-1338
Approximate Formulas for Natural Frequencies of Rectangular Plates with Linearly Varying Thickness
T. Sakata and Y. Sakata
Dept. of Mech. Engrg., Chubu Inst. of Tech., Kusagai, Nagoya-sub., Japan 487, J. Acoust. Soc. Amer., 61 (4), pp 982-985 (Apr 1977) 5 figs, 1 table, 15 refs

Key Words: Rectangular plates, Variable cross section, Natural frequencies

A characteristic equation is derived analytically for a rectangular plate with thickness varying linearly in one direction by using the trigonometric series. Boundary conditions of the plate are simply supported along two opposite sides, free along one side and simply supported or free along the remaining side. By using the results computed numerically from the characteristic equation, approximate formulas are derived for estimating accurately the fundamental natural frequency of the plate.

77-1339
Forced Vibration of Thin, Elastic, Rectangular Plates with Edges Elastically Restrained Against Rotation
E.A. Susemihl and P.A.A. Laura
Universidad de los Andes, Bogota, Colombia, J. Ship Res., 21 (1), pp 24-29 (Mar 1977) 1 fig, 6 refs

Key Words: Rectangular plates, Forced vibration, Galerkin method

Polynomial coordinate functions and the Galerkin method are used to determine the response of a thin, elastic, rectangular plate with edges elastically restrained against rotation and subjected to sinusoidal excitation.

77-1340
Free Vibration of a Circular Disk Loaded at Centre
P.J. George
Engrg. College, Trichur, India, J. Instn. Engr., India, 57 (3), pp 133-136 (Nov 1976) 4 figs, 7 refs

Key Words: Circular plates, Natural frequencies, Transverse shear deformation effects, Rotary inertia effects

A closed form frequency equation is derived for the natural frequencies of axisymmetric flexural vibration of a uniform circular disk of isotropic elastic material loaded at centre with an arbitrary impedance. Mindlin's improved dynamic theory of plates which takes into account the effect of transverse shear and rotary inertia is used. The frequency spectra of the improved theory are compared with those of the classical theory.

77-1341
Flutter and Buckling of General Laminated Plates
J.W. Sawyer
Langley Res. Ctr., NASA, Hampton, VA, J. Aircraft, 14 (4), pp 387-393 (Apr 1977) 10 figs, 1 table, 14 refs

Key Words: Plates, Laminates, Flutter

An anisotropic analysis and solution procedure has been developed using linear small-deflection theory for the buckling and flutter of finite, simply supported laminated plates with arbitrary fiber orientations. The extended Galerkin method is used to obtain approximate solutions to the coupled governing equations.

77-1342
Sound Radiation from Baffled, Thin, Rectangular Plates
M.C. Gomperts
TNO Res. Inst. for Environ. Hygiene, Delft, The Netherlands, Acustica, 37 (2), pp 93-102 (Mar 1977) 14 figs, 1 table, 4 refs

Key Words: Plates, Resonant response, Resonant frequency

The radiation efficiencies of baffled, thin, rectangular plates carrying two-dimensional resonant vibration patterns are determined for five different kinds of edge conditions. For the low frequency range simple approximation formulae are given.

77-1343

Sound Transmission Through Periodically Framed Parallel Plates

G. Lin and J.M. Garrelick

Cambridge Acoustical Assoc., Inc., Cambridge, MA 02138, J. Acoust. Soc. Amer., 61 (4), pp 1014-1018 (Apr 1977) 5 figs, 8 refs

Key Words: Plates, Sound transmission, Walls

The problem of transmission of a plane sound wave through two infinite parallel plates connected by identical periodically spaced frames is solved. Fluid loading within and without the cavity space is taken into account. Numerical results are presented corresponding to a standard double-walled partition. The strengths of the two parallel transmission paths, i.e., the structural path through the studs and the airborne path through the cavity space, are compared.

SPRINGS

77-1344

The Numerical Solution of the Dynamic Response of Helical Springs

S.K. Sinha and G.A. Costello

General Thomas J. Rodman Lab., Rock Island Arsenal, IL, Rept. No. RIA-R-TR-76-045, 44 pp (Dec 1976)

AD-A034 588/4GA

Key Words: Helical springs, Numerical analysis

An analysis was conducted to determine the dynamic response of helical springs under axial impact with particular application to the return spring in the M60A2 tank recoil mechanism. The dynamic behavior of the impacted spring is described by two coupled nonlinear partial differential equations. Two computer solutions to the equations are obtained by the methods of finite differences and nonlinear characteristics. Results of the two numerical techniques are compared with the closed form solution of the linear equations.

77-1345

Measuring Vibration on Soft Seats

E.M. Whitham and M.J. Griffin

Human Factors Res. Unit, Inst. of Sound and Vibration Res., Univ. of Southampton, UK, SAE Paper No. 770253, 12 pp, 5 figs, 11 refs

Key Words: Seats, Vibration measurement

Two experiments have been conducted to assess a method of measuring the whole-body vertical vibration experienced by persons seated on soft seats. The method utilizes a transducer mount located between the seat and the body. Comfort contours obtained on hard flat seats are shown to be applicable to measurements made within a firm bar or plate placed on a cushion beneath the ischial tuberosities of a seated subject. However, since some mounts alter seat transmissibility a firm plate (SIT-BAR) contoured to cause seat compression similar to that produced by the buttocks is recommended for some applications.

STRUCTURAL

(Also see Nos. 1240, 1269, 1343)

77-1346

Frequency Analysis of Coupled Shear Wall Assemblies

Y.K. Cheung, S.G. Hutton, and C. Kasemset

Dept. of Civil Engrg., Univ. of Adelaide, Adelaide, Australia, Earthquake Engrg. and Struct. Dyn., 5 (2), pp 191-201 (Apr-June 1977) 8 figs, 3 tables, 10 refs

Key Words: Walls, Free vibration, Finite strip procedure

The finite strip procedure is used to predict the free vibration response of both planar and non-planar coupled shear wall assemblies. The solid walls are considered as vertical cantilever strips and a comparison is made between modeling the spandrel beams as discrete beams and as an equivalent continuum with orthotropic plate properties. The effects of vertical inertial forces and shear deflection are included, and structures considered may have properties that vary with height. The method presented appears to be more versatile than previously published techniques and numerical comparisons with existing methods indicate the predicted results to be accurate.

77-1347

Behavior of Ten-Story Reinforced Concrete Walls Subjected to Earthquake Motions

J.D. Aristizabal-Ochoa and M.A. Sozen

Dept. of Civil Engrg., Univ. of Illinois, Urbana-Champaign, Rept. No. UILU-ENG-76-2017, Structural Res. Ser-431, 397 pp (Oct 1976)
PB-262 950/9GA

Key Words: Buildings, Walls, Beams, Reinforced concrete, Seismic response, Testing techniques, Test facilities

The response of ten-story reinforced concrete walls coupled by beams to earthquake base motions was investigated through experimental and analytical models. The experimental work involved tests of small-scale ten-story reinforced concrete walls coupled by beams subjected to base motions, simulating one horizontal component of representative earthquake-motion records, on the University of Illinois Earthquake Simulator.

SYSTEMS

ABSORBER

(Also see No. 1361)

77-1348

Controlled, Linear Deceleration with Shock Absorbers

W.J. Chorkey

ACE Controls, Inc., Farmington, MI, Mach. Des., 49 (8), pp 72-77 (Apr 7, 1977) 1 fig, 1 table

Key Words: Shock absorbers

Unlike springs, rubber bumpers, or cylinder cushions, shock absorbers can absorb energy at a uniform rate. Faster deceleration without high shock loads that can damage costly equipment results.

77-1349

Shock-Absorbing Tools Speed Drilling

M.G. Willcox, A.P. Karle, and H.R. Chavez

Johnston Div. of Schlumberger Corp., Houston, TX, Oil and Gas J., 75 (12), pp 149-159 (Mar 21, 1977) 11 figs, 5 refs

Key Words: Drills, Shock absorbers

Shock-absorbing subs reduce damage from drill-string vibration under high loads. The use of a shock absorber for rough drilling conditions can boost drilling rate through the higher weights and speeds it allows.

77-1350

Isolation and Absorption of Machinery Vibration

J.C. Snowdon

Applied Res. Lab., Pennsylvania State Univ., University Park, PA, Rept. No. TM-76-188, 54 pp (July 1, 1976)
AD-A034 489/5GA

Key Words: Vibration absorption (equipment), Vibration isolators, Dynamic vibration absorbers, Machinery vibration

The isolation of machinery vibration from rigid and nonrigid substructures is described in uncomplicated terms. One- and two-stage mounting systems, single and multiple antivibration mountings, and beamlike and platelike substructures are examined. A machine and the intermediate mass of a two-stage mounting system are considered to be supported by flanges or feet to demonstrate the loss in isolation that can occur if the flanges are not rigid but are multiresonant because of their poor design. The use of conventional dynamic absorbers to reduce the vibration of such structural members as beams (rails and stanchions) and circular plates (bulkheads) is discussed. A novel dynamic vibration absorber is described that comprises a damped circular plate loaded centrally by a lumped mass and clamped at its perimeter to the vibrating item or structure of concern.

NOISE REDUCTION

(Also see Nos. 1247, 1396, 1403)

77-1351

Noise and Vibration Control of Large Ventilation Plant

D.A. Richardson

Atkins Res. and Dev., Noise Control, Vib. and Insul., 8 (3), pp 84-86 (Mar 1977) 4 figs

Key Words: Fans, Noise reduction, Buildings

Several methods of noise and vibration reduction in commercial buildings with plant rooms are indicated. The plant rooms contain anything from a toilet extract fan, a boiler, or a lift motor to a full air conditioning plant. A typical installation is described, where noise reduction is achieved by mounting the fan and the enclosure separately to the floor.

AIRCRAFT

(Also see Nos. 1247, 1250, 1251, 1253, 1261, 1262,1297, 1351, 1378)

77-1352

The Engine-Over-The-Wing Noise Problem

A.D. Rawlins

Dept. of Math., Univ. of Dundee, Dundee DD1 4NH, Scotland, UK, J. Sound Vib., 50 (4), pp 553-569 (Feb 22, 1977) 8 figs, 12 refs

Key Words: Aircraft noise, Mathematical models

The problem of diffraction of a sound wave by a strip in a moving fluid is investigated. The sound source is a line source which is at a fixed finite distance from the strip. This system is in a moving subsonic fluid, and a vortex sheet is assumed to be attached to the trailing edge. The above problem is a model for the situation when an engine is at a fixed distance and orientation above an aircraft wing, the aircraft being in flight.

77-1353

Considerations for the Application of Finite Element Beam Modeling to Vibration Analysis of Flight Vehicle Structures

R.G. Kvaternik

Langley Res. Ctr., NASA, Langley Station, VA, Rept. No. NASA-TM-X-73980, 101 pp (Nov 1976) N77-14518

Key Words: Flight vehicles, Aircraft, Finite element technique, Mathematical models, Beams

The manner of representing a flight vehicle structure as an assembly of beam, spring, and rigid-body components for vibration analysis is described. The development is couched in terms of a substructures methodology which is based on the finite-element stiffness method. The particular manner of employing beam, spring, and rigid-body components to model such items as wing structures, external stores, pylons supporting engines or external stores, and sprung masses associated with launch vehicle fuel slosh is described by means of several simple qualitative examples. A detailed numerical example consisting of a tilt-rotor VTOL aircraft is included to provide a unified illustration of the procedure for representing a structure as an equivalent system of beams, springs, and rigid bodies, the manner of forming the substructure mass and stiffness matrices, and the mechanics of writing the equations of constraint which enforce deflection compatibility at the junctions of the substructures.

77-1354

Flutter Investigation of a Combat Aircraft with a Command and Stability Augmentation System

A. Lotze, O. Sensburg, and M. Kuhn

Airplane Div., Messerschmitt-Bolkow-Blohm GmbH, Munich, Germany, J. Aircraft, 14 (4), pp 368-374 (Apr 1977) 15 figs, 14 refs

Key Words: Aircraft, Flutter

Modern airplanes like the sweepable-wing combat aircraft Tornado are using sophisticated power control and automatic control systems, which basically are designed to maneuver the aircraft and to provide sufficient damping for the rigid body modes. Since the sensors are attached to a flexible structure, motions of the elastic aircraft also are picked up and may be modified by the system. In order to avoid instabilities it is necessary to predict the response of the airplane with the control system and to correlate with test data. An analytical approach for the complete system including unsteady aerodynamic forces is presented. The elastic structure is described by normal modes which have been modified by results of a ground resonance survey. Results of open- and closed-loop calculations are demonstrated by Nyquist and common flutter plots and compared with test data.

BIOENGINEERING

(Also see No. 1313)

77-1355

Hand-Arm Vibration. Part I: Analytical Model of the Vibration Response Characteristics of the Hand

D.D. Reynolds and R.H. Keith

Dept. of Architectural Engrg., Univ. of Texas at Austin, TX 78712, J. Sound Vib., 51 (2), pp 237-253 (Mar 22, 1977) 10 figs, 3 tables, 16 refs

Sponsored by the National Institute for Occupational Safety and Health, Public Health Service, Dept. of Health, Education and Welfare

Key Words: Human hand, Mathematical models, Vibration response

A three-degree-of-freedom, mass-spring-damper, lumped parameter model of the vibration response of the hand due to a sinusoidal input has been developed. This model predicted the response characteristics of the hand between the frequencies of 5 Hz to 1000 Hz and it was fairly descriptive of the physical orientation and coupling that existed between the epidermis, dermis, subcutaneous and muscle tissues and the skeletal system of the fingers and hand.

77-1356

Hand-Arm Vibration. Part II: Vibration Transmission Characteristics of the Hand and Arm

D.D. Reynolds and E.N. Angevine

Dept. of Architectural Engrg., Univ. of Texas at Austin, TX 78712, J. Sound Vib., 51 (2), pp 255-265 (Mar 22, 1977) 8 figs, 5 refs

Key Words: Human hand, Vibration measurement

A method for measuring the vibration levels due to vibration induced into the hand that were transmitted to specified locations on the hand and arm is presented. This method employed the use of subminiature clamped piezo-resistive accelerometers which weigh less than 0-3 g.

77-1357

Hand-Arm Vibration. Part III: Subjective Response Characterisitcs of Individuals to Hand-Induced Vibration

D.D. Reynolds, K.G. Standlee, and E.N. Angevine

Dept. of Architectural Engrg., Univ. of Texas at Austin, TX 78712, J. Sound Vib., 51 (2), pp 267-282 (Mar 22, 1977) 14 figs, 15 refs

Sponsored by the National Inst. for Occupational Safety and Health, Public Health Service, Dept. of Health, Education and Welfare

Key Words: Human hand, Vibration response

Tests were developed and conducted to determine an individual's subjective response to hand-induced vibration. These tests included equal sensations, threshold and annoyance tests. From the results of these tests, it was possible to make statements with regard to the physiological mechanisms that were responsible for an individual's perception of both discrete frequency and broad band vibration that was directed into the hand. By using the results of this and past investigations, it was possible to discuss an individual's perception of hand-induced vibration relative to the nature of the energy transfer that occurred between a vibrating handle and the hand.

BUILDING

(Also see Nos. 1246, 1249, 1351)

77-1358

A Study of the Vibration Characteristics of Two Multistory Buildings

D.A. Foutch

Ph.D. Thesis, Calif. Inst. of Tech., 210 pp, 1977
UM 77-7391

Key Words: Multistory buildings, Forced vibration, Vibration tests, Finite element technique

Forced vibration tests and associated analysis of two multistory buildings are described. In one case, the dynamic properties of the building measured during the tests are compared to those predicted by simple analytical models. A three-dimensional finite element model of the second building was constructed for the purpose of evaluating the accuracy of this type of analysis for predicting the observed dynamic properties of the structure.

77-1359

Dynamic Instability and Ultimate Capacity of Inelastic Systems Parametrically Excited by Earthquakes. Part II

F.Y. Cheng and K.B. Oster

Dept. of Civil Engrg., Missouri Univ. at Rolla, MO, Rept. No. Civil Engrg. Study-76-1, 339 pp (Aug 1976) (see also rept. dated Aug 1973, PB-261 096)
PB-261 097/0GA

Key Words: Multistory buildings, Framed structures, Earthquake response, Computer programs

An analytical study is presented for the behavior of multistory framed structures subjected to the interaction of horizontal and vertical components of an earthquake. Frameworks having three to ten stories and one to three bays are studied on the basis of two lumped mass models with elastic, elasto-plastic and bilinear material behavior. The studies include the characteristics of input energy, kinetic energy, elastic strain energy, dissipated strain, and damping energy; the reduction of plastic moment capacity of columns; ductility and excursion rations; and the P-delta effect.

77-1360

Evaluation of Safety of Reinforced Concrete Buildings to Earthquakes

M. Portillo Gallo

Ph.D. Thesis, Univ. of Illinois at Urbana-Champaign, IL, 123 pp, 1976
UM 77-9146

Key Words: Reinforced concrete, Buildings, Earthquake resistant structure

Current earthquake-resistant provisions for reinforced concrete structures are examined in terms of the estimated probability of failure. Detailed examination and assessment of the variabilities of loading and structural properties, as well as of the inaccuracies of load and resistance analysis methods are performed. Various dead and live load models are reviewed and used in evaluating such loads for seismic consideration. Previous studies on strength of reinforced concrete elements are used for information on the resistance.

77-1361
Design Targets for Background Noise Levels in Buildings
T.J.B. Smith
Sound Res. Labs. Ltd., Noise Control, Vib. and Insul., 8 (3), pp 88-91 (Mar 1977) 4 figs, 2 tables, 5 refs

Key Words: Buildings, Noise reduction

This paper reviews various procedures which have been developed for establishing background noise criteria. In the two tables a compilation of background noise design targets is presented, which is suitable for most commercial applications.

EARTH

77-1362
Vertical Vibration of Floating Piles
M. Novak
Univ. of Western Ontario, London, Ontario, Canada, ASCE J. Engr. Mech. Div., 103 (1), pp 153-168 (Feb 1977) 11 figs, 11 refs

Key Words: Pile structures, Interaction: soil-structure, Damping, Stiffness

An approximate analytical solution is presented for the vertical dynamic response of a floating pile. The dynamic stiffness and damping of the soil-pile system are also obtained. The results are compared with experiments.

FOUNDATIONS

77-1363
Nuclear Turbine-Generator Foundation Tests
I.K. Aneja and B.W. Dimmick
Westinghouse Electric Corp., STDE, Lester, PA, ASCE J. Engr. Mech. Div., 103 (2), pp 243-255 (Apr 1977) 8 figs, 3 refs

Key Words: Mode shapes, Natural frequencies, Foundations, Nuclear power plants, Computer programs

This paper describes briefly the fabrication, preparation, and erection details for a 1/10th scale plastic (polystyrene) model of a steel foundation supporting a nuclear turbine-generator-exciter unit. The foundation consists of box-section beams and columns with a large number of diaphragms. Natural frequencies of the foundation model with column bases fixed to the blocks were obtained with and without mass representation for the turbine-generator-exciter unit on the model deck. Selected (fundamental) mode shapes of the model were obtained experimentally for the two test cases. Details of the test procedure and instrumentation used are also given in this paper. Corresponding analytical data for the model obtained by using NASTRAN, the finite element computer program, are examined briefly in this paper. Comparison between the experimental and analytical data (frequencies, mode shapes) given in the paper showed excellent agreement.

HELICOPTERS

(Also see Nos. 1310, 1408)

77-1364
Scale Tests of a Multi-Seat Airbag
C.W. Stammers
School of Engrg., Univ. of Bath, Bath BA2 7AY, UK, J. Sound Vib., 51 (1), pp 117-122 (Mar 8, 1977) 4 figs, 7 refs

Key Words: Helicopter seats, Inflatable structures, Natural frequency, Damping

The natural frequency and damping of symmetrical and asymmetrical modes of a six seat airbag have been measured by using an approximately half-scale model. Pressure relief by venting of air is also examined, and the effect of changes in scale and geometry are discussed.

77-1365
The Control of Vibration in Helicopters
D.E.H. Balmford
Westland Helicopters Ltd., Aeronaut. J., 81 (794), pp 63-67 (Feb 1977) 12 figs

Key Words: Helicopter vibration, Vibration control

The discussion in this paper is restricted to minimization of the amplification of the basic aerodynamic loads due to the dynamic response of the rotor blades; and minimization of the response of the airframe to rotor oscillatory loads which reinforce and are transmitted to the airframe.

HUMAN

77-1366
Repeatability of Setup and Stability of Anthropometric Landmarks and Their Influence on Impact Response of Automotive Crash Test Dummies
S. Backaitis and E. Enserink
National Highway Traffic Safety Admin., SAE Paper No. 770260, 24 pp, 8 figs, 4 refs

Key Words: Anthropomorphic dummies, Collision research (automotive)

Dummy positioning repeatability, dynamic stability during runup to crash speeds and the sensitivity of dummy crash response were investigated using precision (forced indexing) and conventional (self-centering) setup procedures. The static repeatability and dynamic stability tests were performed in ten domestic and imported production vehicles. The sensitivity of dummy response to setup methods was investigaed in sled tests. Test results indicate that the precision procedure causes higher levels of static dispersion and dynamic instability of anthropometric landmarks of dummies setup in production vehicles and only marginally improved dummy response in the HI-G sled environment.

77-1367
Dummy Design and Reaction at Impact Simulation
V.S. Gersbach and P.M. Müsseler
Bayerische Motoren Werke AG, SAE Paper No. 770262, 15 pp, 34 figs, 25 refs

Key Words: Anthropomorphic dummies, Collision research (automotive)

The influence of neck flexibility of the Hybrid-II-dummy on the Head Injury Criterion is investigated by means of sled tests. Characteristic properties of this dummy type with regard to reproducibility and durability are discussed; kinematic properties of spine and rib cage are compared with the human equivalents. Finally, adjustability of this dummy type and various test methods, especially neck tests, are closely examined.

77-1368
An Assessment of the Relationship Between Frontal Impact Severity and Injury Level
J.C. Marsh IV, K.L. Campbell, and B.C. Kingman
Highway Safety Res. Inst., Univ. of Michigan, Ann Arbor, MI, SAE Paper No. 770156, 16 pp, 4 figs, 24 refs

Key Words: Collision research (automotive), Human response

The relationship between crash severity and injury level is illustrated using the Restraint System Evaluation Study (RSES) data and Texas police-reported data. The RSES data are used to demonstrate that the probability of an injury (or fatality) is a function of both the risk of injury, given a set of crash factors, and crash exposure, or the chance of those factors occurring.

77-1369
Validation of Human Body Modeling for Dynamic Simulation
D.H. Robbins, R.O. Bennett, and J.M. Becker
Highway Safety Res. Inst., The Univ. of Michigan, Ann Arbor, MI, SAE Paper No. 770058, 22 pp, 1 fig, 17 refs

Key Words: Collision research (automotive), Mathematical models, Human response

The two purposes of this paper are to discuss the state of the art of correlation and validation of mathematical crash victim simulators and to describe recently developed software, the Validation Control Language or VCL, which is designed to aid the user as he conducts correlation or validation studies.

ISOLATION

(Also see Nos. 1257, 1350)

77-1370
Mechanical Antivibration Filter Design Using Electrical Network Synthesis Techniques
C.B. Putman
Applied Res. Lab., Pennsylvania State Univ., University Park, PA, Rept. No. TM-76-162, 100 pp (Apr 7, 1976)
AD-A034 460/6GA

Key Words: Vibration isolators, Structural synthesis

Two methods are presented by which mechanical low-pass filters can be designed using electrical network synthesis techniques. The desired response can be any low-pass filter function that is realizable as a planar reactive ladder network. The resultant response of the synthesized network will be slightly different from the desired response, but this difference is predictable and can be taken into account when considering the specifications for the design of the filter.

77-1371

Resilient Mounting of Machinery on Platelike and Modified Platelike Substructures

J.C. Snowdon

Applied Res. Lab., The Pennsylvania State Univ., University Park, PA 16802, J. Acoust. Soc. Amer., 61 (4), pp 986-994 (Apr 1977) 11 figs, 9 refs (See also: Penn. State U. TM 76-278, 38 pp, Nov 1976, AD-A035 224)

Key Words: Vibration isolation, Engine mounts, Dynamic vibration absorption (equipment), Machinery

The problem of isolating machinery vibration from platelike substructures is analyzed. Simply supported, internally damped, square, rectangular, and circular plates are considered, as are rectangular plates with rigid cross members that divide the plates into separate quadrants. The machinery is supported either by eight or by four antivibration mounts located symmetrically about the plate centers. The attachment of dynamic vibration absorbers or lumped masses to the plates at each mount location is shown to be effective in reducing the force transmitted to the plate boundaries. The dynamic absorbers are tuned to suppress transmissibility at the fundamental resonance of the plate of concern, whereas the lumped masses become effective at frequencies above this resonance where their impedance predominates that of the plate.

METAL WORKING & FORMING

(Also see No. 1283)

77-1372

Grinding Dynamics

D.L. Brown

Ph.D. Thesis, Univ. of Cincinnati, OH, 419 pp, 1976 UM 77-7347

Key Words: Grinding (material removal), Self-excited vibration

The work described in this thesis concerns the vibrational dynamics associated with the grinding process. It includes a model for forced vibrations; predictions for the rate of growth of unstable self-excited vibrations; determination and measurement of important grinding parameters; verification of the grinding model with experimental measurement; and development of experimental techniques and equipment for measuring grinding machine characteristics. A complete dynamic grinding analysis was performed which includes the development of an analytical model, experimental verifications of the model, and design considerations based upon the model. A second but an equally important contribution has been the development of advanced digital experimental testing techniques and equipment. These developments have broad applications outside of the machine tool industry.

77-1373

Noise Generated by a Laboratory Drop Hammer and Its Interrelation with the Structural Dynamics and Process Parameters

V. Gregorian, M.M. Sadek, and S.A. Tobias

Mech. Engrg. Dept., Univ. of Birmingham, South West Campus, B15 2TT, UK, Intl. J. Mach. Tool Des. Res., 16 (4), pp 301-318 (1976) 16 figs, 7 refs

Key Words: Hammers, Machine tools, Noise generation

The noise generated during an upsetting process on a laboratory drop hammer is measured, analyzed and predicted from first principles. The theory developed relates the modes of vibration of the hammer structure with the noise perceived by an operator at any specified position in space. It is based on a lumped constant representation of the machine structure coupled with a non-linear variation of the forming load as a function of the instantaneous billet deformation. Experimental and theoretical work cover the determination of the relationship between the peak sound pressure and the input energy, as well as the efficiency of energy transfer. Theoretical predictions agree reasonably well with the experimental results.

77-1374

Chatterfree Working with Drill Rods by Periodical Variation of Rotational Speed

H. Grab

VDI-Z, 119 (6), pp 309-314 (1977) 14 figs, 3 refs

Key Words: Stick-slip response, Metal working

Violent self-excited oscillations frequently occur during machining between tool and work piece which are called chatter (stick slip) oscillations. The appearance of such chatter oscillations is mostly accompanied by disadvantageous consequences: The surface quality of the work piece becomes faulty. The wear and tear of the tools and of the machine increases; sometimes tool fracture takes place after a short time. This contribution is concerned with one of several possibilities to avoid chatter oscillations.

PUMPS, TURBINES, FANS, COMPRESSORS

(Also see Nos. 1278, 1309, 1351)

77-1375

Flow-Induced Vibration in LMFBR Steam Generators: A State-of the-Art Review

Y.S. Shin and M.W. Wambsganss

Components Tech. Div., Argonne National Lab., Argonne, IL 60439, Nucl. Engr. Des., 40 (2), pp 235-284 (Feb 1977) 38 figs, 119 refs

Key Words: Boilers, Fluid-induced vibration

This state of the art review identifies and discusses existing methods of flow-induced vibration analysis applicable to steam generators, their limitations and base-technology needs. Also included are discussions of five different LMFBR steam generator configurations and important design considerations, failure experiences, possible flow-induced excitation mechanisms, vibration testing and available methods of vibration analysis. The objectives are to aid LMFBR steam generator designers in making the best possible evaluation of potential vibration in steam generator internals, and to provide the basis for development of design guidelines to avoid detrimental flow-induced vibration.

77-1376

Predicting Response of a Proposed Hydraulic Control System Using Bond Graphs

B.W. Barnard and P. Dransfield

Mech. Engrg. Dept., Caulfield Inst. of Tech., Australia, J. Dyn, Syst., Meas. and Control, Trans. ASME, 99 (1), pp 1-8 (Mar 1977) 7 figs, 5 refs

Key Words: Hydraulic equipment, Mathematical models, Bond graph technique

Dynamic response is an important criterion of quality for many hydraulic control systems. The bond graph modeling technique followed by digital simulation of the model is applied to a hydraulic system proposed for a particular task. Predicted response and subsequently measured response are given, compared, and discussed. Only generally available data and parameter assessment procedures were used for the prediction.

77-1377

Further Studies of Static to Flight Effects on Fan Tone Noise Using Inlet Distortion Control for Source Identification

B.K. Hodder

Ames Res. Ctr., NASA, Moffett Field, CA, Rept. No. NASA-TM-X-73183; A-6821, 42 pp (Dec 1976) Sponsored by Army Air Mobility R and D Lab., Moffett Field, CA

N77-14027

Key Words: Fans, Noise source identification

Current experimental investigations have linked static inflow distortion phenomena such as the ground vortex, atmospheric turbulence, and teststand structure interference to the generation of fan tone noise at the blade passing frequency. Since such distortions do not exist in flight, it is important to remove them from the static test environment and thereby improve the static-to-flight tone-noise correlation. In the course of providing evidence for this position, a recent investigation used a distortion control inlet with a modern day turbofan engine to assess atmospheric turbulence effects. Although the initial results were encouraging, they were incomplete. The present investigation continues this work and shows more completely the effect of atmospheric turbulence on tone-noise generation. Further, use is made of the distortion control inlet to identify other competing tone-noise sources in the test engine such as a rotor-core stator interaction which was confirmed by engine modifications.

77-1378

Ideal Attenuation Characteristics of Sound Attenuators for Ventilation and Air Conditioning Plants

W. Finkelstein

Res. and Dev. Ctr., Trox Brothers, Germany, Noise Control, Vib. and Insul., 8 (3), pp 93-97 (Mar 1977) 12 figs, 1 table

Key Words: Sound attenuation, Fans

A splitter sound attenuator was developed with an insertion loss spectrum well matched to the acoustic requirements of the ventilation and air conditioning systems. Additionally it has essentially higher attenuation values in the frequency range 250 Hz than, for example, conventional absorption units with the same splitter thickness and airways width.

77-1379

Vibrations of an Elastic Rail Induced by a Long Train (Angefachte Schwingungen einer Elastischen Fahrbahn bei der Überfahrt eines Langen Zuges)

G. Schweitzer

Inst. für Mechanik, Technische Universität München, Arcisstr. 21, D-8000 München 2, Bundesrep Deutschld., Ing. Arch., 46, pp 53-64 (1977) 8 figs, 11 refs (In German)

Key Words: Interaction: rail-wheel

The non-uniform mass distribution of a long train is modeled by a periodic continuous load. This moving load can cause resonance and instability of the vibrations of a bridge or a beam-elevated guideway. The amplitude of vibration increases with time, and therefore with the length of the crossing train. An approximation is given for that length where the vibration amplitude reaches some critical value.

77-1380

Investigation of the Dynamics of Magnetically Levitated Vehicles on Flexible Guideways (Untersuchungen zur Dynamik von Magnetschwebefahrzeugen auf Elastischen Fahrwegen)

K. Popp, R. Habeck, and W. Breinl

Lehrstuhl B f. Mechanik, Technische Universität München Arcisstr. 21, D-8000, München 2, Bundesrepublik Deutschland, Ing. Arch., 46, pp 1-19 (1977) 12 figs, 16 refs (In German)

Key Words: Surface effect machines, Mathematical models, Periodic response

Methods are developed to investigate the dynamical behavior of magnetically levitated vehicles on flexible guideways. Starting with the analysis of vehicle, suspension and guideway the mathematical model of the closed-loop system is obtained in a systematic way. The efficiency of the methods developed for stability and response is demonstrated by an example.

77-1381

Linear Induction Motor Research Vehicle Speed Upgrading Tests (190 to 250 Mph)

C.C. Chi

AiResearch Mfg. Co. of California, Torrance, CA 90500, Rept. No. 74-11035-Rev-1, FRA/ORD-76/268, 105 pp (June 1976) (see also report dated June 1973, PB-224 878)

PB-261 852/8GA

Key Words: Railroad trains, High speed transportation, Dynamic stability, Experimental data

The linear induction motor research vehicle (LIMRV) was subjected to a series of test runs at speeds of 190 to 250 mph on the Department of Transportation 6.2-mile-long, standard gauge railroad track at the Transportation Test Center, Pueblo, Colorado. High-speed dynamic performance data on the vehicle, trucks, suspension systems, and LIM guidance system were acquired by means of instrumentation that measured accelerations and displacements.

REACTORS

(Also see No. 1363)

77-1382

Basic Ideas of a Philosophy to Protect Nuclear Plants Against Shock Waves Related to Chemical Reactions

D. Jungclaus

Institut f. Reaktorsicherheit der Technischen Überwachungs- Vereine e.V., D-5000 Köln, West Germany, Nucl. Engr. Des., 41 (1), pp 75-89 (Mar 1977) 12 figs, 3 tables, 9 refs

Key Words: Nuclear power plants, Blast resistant structures

The designing of nuclear power plant installations to withstand the loading which is caused by explosions is discussed. In addition exclusion regions around nuclear power plants within which no storage of explosive materials or transportation that is connected with high risk is allowed can be defined.

77-1383

Vibration- and Pressure Signals as Sources of Information for an On-Line Vibration Monitoring System in PWR Power Plants

V. Bauernfeind

Lab. f. Reaktorregelung u. Anlagensicherung, T.U. München, 8046 Garching Forschungsgelände, Fed. Republic of Germany, Nucl. Engr. Des., 40 (2), pp 403-420 (Feb 1977) 25 figs, 9 refs

Key Words: Nuclear power plants, Diagnostic techniques

Two mechanical models, a pendular and a vertical one described herein simulate the two kinds of vibration found in nuclear power plants. The calculated frequency response is compared with the measured vibrations.

77-1384

TUGSIM-10, A Computer Code for Transient Analysis of Closed Gas Turbine Cycles and Specific Applications

J.F. DuPont, R. Jeanmonod, and H.U. Frutschi
Swiss Federal Inst. for Reactor Res., CH-5303, Wurenlingen, Switzerland, Nucl. Engr. Engr. Des., 40 (2), pp 421-430 (Feb 1977) 10 figs, 9 refs

Key Words: Nuclear power plants, Turbine components, Transient response, Computer programs

A code has been developed to compute the kinetic and thermohydraulic transients in a nuclear gas turbine power plant for both operational and accidental conditions. A depressurization accident analysis demonstrates the performance of the code and shows how the core may be cooled by coolant circulation throught the turbomachinery, using the afterheat to drive the gas turbine. Emergency shut-down calculations for a 30 MW(e) fossil fuel plant are compared with measurements.

RECIPROCATING MACHINE

(Also see Nos. 1239, 1281)

77-1385

Core Engine Noise Program. Volume 3: Prediction Methods. Supplement 1: Extension of Prediction Methods

J.J. Emmerling, S.B. Kazin, and R.K. Matta
Advanced Engrg. and Tech. Programs Dept., General Electric Co., Cincinnati, OH, Rept. No. AD-A030-376/8; R76AEG305; FAA-RD-74-125-Vol-3-Suppl-1, 51 pp (Mar 1976)
N77-14028

Key Words: Engine noise, Noise prediction

The core noise prediction technique described was validated using several additional sets of engine data. The data included discernible core noise at high power settings and were derived from both General Electric and external tests, on engines by manufacturers. The three line power level prediction method was collapsed to single unified line prediction through addition of a turbine work extraction term to account for the low frequency noise attenuation due to turbine blading. Data from combustor component tests were compared to engine noise levels and found to indicate significant attenuation of low frequency noise in propagation through turbine stages. An analytical method for predicting this low frequency noise attenuation is provided.

77-1386

The Use of Digital Fourier Transform Methods in Engine Noise Research

J.Y. Chung
Fluid Dynamics Res. Dept., General Motors Res. Labs., SAE Paper No. 770010, 12 pp, 11 figs, 11 refs

Key Words: Engine noise, Fourier transformation, Digital techniques

Recent developments by the author in the application of digital Fourier transform (DFT) methods, i.e., coherence and transfer function techniques to the investigation of noise from an engine are discussed. The transfer functions are determined empirically and they can be used to determine the mechanism of noise generation of an engine.

ROAD

(Also see Nos. 1250, 1251, 1254, 1255, 1256, 1257, 1263, 1366, 1367, 1368, 1369)

77-1387

Computer Simulation of Car-To-Car Collisions

J.E. Greene
Calspan Corp., Buffalo, NY, SAE Paper No. 770015, 16 pp, 24 figs, 10 refs

Key Words: Collision research (automotive), Computerized simulation

Verification and application of computerized car-to-car collision simulations are the main subjects of this paper. The simulations are based on a lumped mass, resistive element modeling approach. Direct comparisons of simulation results with corresponding crash test data are presented for a number of impact conditions. Specific simulation applications are also discussed, one dealing with intervehicular collision compatibility and another involving the investigation of structural variation effects.

77-1388

Automobile Consumer Information Crash Test Program. Volume 1

N.E. Shoemaker, M.O. Ryder, and N.J. DeLeys
Calspan Corp., Buffalo, NY, Rept. No. CALSPAN-ZT-5561-V-30, DOT-HS-802 010-A, 27 pp (Nov 1976)
PB-262 066/4GA

Key Words: Collision research (automotive), Automobiles, Crashworthiness

The objectives of the program were to generate experimental test data on recent intermediate size automobiles in the areas of damage susceptibility, crashworthiness and repairability and to demonstrate the capability of existing simulation models for predicting the dynamic responses of the vehicles and occupants. The full-scale crash testing program included frontal barrier and car-to-car front-to-side and front-to-rear impacts in 22 tests of 1973 and 1974 models of Plymouth Satellite and Ford Torino vehicles. The vehicle structure and occupant computer models are briefly described and comparisons of simulated and actual crash test results are presented. The methodology of static crush tests that were performed to obtain data on the force-deflection properties of the major vehicle structural components for input to the vehicle response models is also briefly described.

77-1389

Automobile Consumer Information Crash Test Program. Volume II

N.E. Shoemaker, M.O. Ryder, and N.J. DeLeys
Calspan Corp., Buffalo, NY, Rept. No. CALSPAN-ZT-5561-V-29, DOT-HS-802 011-A, 270 pp (Nov 1976)
PB-262 411/2GA

Key Words: Collision research (automotive), Automobiles, Crashworthiness

The objectives of the program were to generate experimental test data on recent intermediate size automobiles in the areas of damage susceptibility, crashworthiness and repairability and to demonstrate the capability of existing simulation models for predicting the dynamic responses of the vehicles and occupants. The full-scale crash testing program included frontal barrier and car to car front-to-side and front-to-rear impacts in 22 tests of 1973 and 1974 models of Plymouth Satellite and Ford Torino vehicles. The vehicle structure and occupant computer models are briefly described and comparisons of simulated and actual crash test results are presented in this report. The methodology and results of static crush tests that were performed to obtain data on the force-deflection properties of the major vehicle structural components for input to the vehicle response models are also presented.

77-1390

Rear Body Construction of Sub-Compacts and Fuel System Integrity in Rear End Collisions

K. Arima, K. Seo, and T. Arakawa
Toyota Motor Co., Ltd., Japan, SAE Paper No. 770171, 16 pp, 16 figs, 2 refs

Key Words: Collision research (automotive), Fuel tanks

According to the investigation and analysis of rear moving barrier collision experiments with sub-compacts which were of front-engine, rear drive, and unitary construction, and which had two different types of conventional fuel tank arrangements (either in the luggage compartment or under the rear floor panel behind the rear axle), it was confirmed that further improvement in fuel system integrity could be achieved by controlling rear body crashworthiness corresponding to each fuel tank arrangement. Especially with the second type of arrangement, crash energy must be absorbed by body deformation both in front of and behind the tank, while at the same time deformation of the rear floor surrounding the tank and the tank itself must be prevented.

77-1391

Air Bag Update - Recent Crash Case Histories

G.R. Smith
Environmental Activities Dept., General Motors Corp., SAE Paper No. 770155, 12 pp, 11 figs

Key Words: Collision research (automotive), Air bags (safety restraint systems)

About 11,000 air cushion-equipped cars have been put on the road by General Motors, including fleet Chevrolets in the field trial program and privately owned 1974-76 Oldsmobiles, Buicks, and Cadillacs. Although these vehicles have accumulated over 400 million car miles, the total is very small when compared with the mileage being driven by the entire vehicle population. Therefore, statistically valid conclusions cannot yet be drawn about the safety benefits of the system. Nevertheless, sampling of accidents illustrates the protection provided by the air cushion in a variety of situations.

77-1392

Energy Absorption of High-Strength Steel Tubes Under Impact Crush Conditions

R.C. VanKuren and J.E. Scott
Research Dept., Bethlehem Steel Corp., SAE Paper No. 770213, 12 pp, 12 figs, 3 refs

Key Words: Collision research (automotive), Energy absorption, Impact tests

The energy absorption of automotive sheet steels was determined at impact speeds to 40 mph by crushing tubular structures at 70 and - 40 F. The test program was designed to provide an intermediate step between tensile and vehicle tests aimed at understanding material behavior at high impact speeds.

77-1393

Mathematical Optimization of Safety Belts (Mathematische Optimierung von Sicherheitsgurten)

P. Niederer

Automobiltech. Z., 79 (2), pp 69-71 (Feb 1977) 4 figs, 11 refs

Key Words: Seat belts, Computerized simulation

For the analysis of crash victim dynamics, computerized simulations can be of great help. The new-developed program, Program for the Simulation and Optimization of Safety Belts, is described and results regarding the acting forces, severity indices, and the reversibly and irreversibly stored energy are discussed. The program calculates the motional sequence of a crash victim in two dimensions. Two- and threepoint belts with independent shoulder and lap belt or with a single strap, as well as systems with plastic anchors or with a kneebar can be simulated.

77-1394

Non-Linear Model Formulation for the Static and Dynamic Analyses of Front Suspensions

K.N. Morman, Jr.

Ford Motor Co., SAE Paper No. 770052, 16 pp, 10 figs, 8 refs

Key Words: Suspension systems (vehicles), Mathematical models, Computer programs

A three degree-of-freedom mathematical model formulation for a double-wishbone front suspension is presented which treats the effects of the tire vertical stiffness, the fore-and-aft bushing compliance in the lower arm, the compliance in a steering linkage and the inertia of the suspension links. The model equations are derived retaining all nonlinearities associated with large changes in the geometric configuration of the suspension system and are solved within a digital computer program which computes the suspension force and displacement response to prescribed ground terrain inputs at the tire patch. Results obtained with the computer model are presented and compared with test measurements.

77-1395

Dynamic Analysis of a Three-Dimensional Vehicle Model Undergoing Large Deflections

Y.O. Bayazitoglu and M.A. Chace

Brown & Root, Inc., SAE Paper No. 770051, 8 pp, 13 figs, 9 refs

Key Words: Automobiles, Suspension systems (vehicles), Mathematical models, Computerized simulation

This paper outlines a mathematical model and an associated digital computer simulation of an automobile in which the effect of large, three-dimensional deflection and the complete geometric detail of the front suspension are considered. Three-dimensional generalized d'Alembert Force expressions are used in the formulation of the differential equations representing the effects of dynamics and loop constraint.

77-1396

Experimental and Theoretical Analysis on Independent Rear Suspension and Body Structure to Reduce Interior Noise

M. Sano, Y. Fujiwara, and A. Naka

Nissan Motor Co., Ltd., Japan, SAE Paper No. 770177, 16 pp, 23 figs, 2 refs

Key Words: Automobile noise, Suspension system (vehicles), Noise reduction

A theoretical and experimental vibration analysis was carried out on the vehicle equipped with independent rear suspension in order to reduce the interior noise. These results were applied to the actual new type of vehicle and its interior noise was measured and three-four dB(A) of noise reduction was obtained.

77-1397

On Factors of Noise Emitted by a Small Vehicle and Noise Level Simulation of Pass-By Test

K. Masuko and T. Abe

Nissan Motor Co., Ltd., Japan, SAE Paper No. 770011, 16 pp, 24 figs, 2 refs

Key Words: Ground vehicles, Automobiles, Noise reduction

To achieve a reduction in the exterior noise of a small vehicle at an early stage of design, we made an attempt to estimate the pass-by noise of the vehicle (ISO R-362 test standards) from measurements of the noise of the engine and exhaust system units. The factors producing exterior vehicle noise, viz., operating condition, noise source and noise propagation were considered.

77-1398

Use of Coherence and Frequency Response Functions to Locate and Define Vibration Noise Sources in Rolling Tires

A.C. Eberhardt and W.F. Reiter

Mech. and Aerospace Engrg., North Carolina State Univ., Raleigh, NC, SAE Paper No. 770027, 7 pp, 11 figs, 6 refs

Key Words: Automobile tires, Vibration measurement, Noise measurement

The procedure for measuring and analyzing in-service tire vibration and sound data is described. Signal analysis techniques are applied to obtain tire vibration spectral histories, vibration-to-sound coherence, and vibration frequency response functions. Evaluation of the coherence function demonstrates the existence of a statistical relationship between tire vibration and sound. Vibration spectral histories display the decay of energy in the tire structure. Use is made of the frequency response function to determine the relative levels of vibration in the tread and sidewall regions. These results define the vibration noise source location and size.

77-1399

Tracked Vehicle Ride Dynamics Computer Program

P. Wheeler

Chrysler Corp., SAE Paper No. 770048, 8 pp, 8 figs, 6 refs

Key Words: Tracked vehicles, Ride dynamics, Road roughness, Mathematical models, Computer programs

A mathematical model has been developed and programmed on the digital computer to simulate vehicle dynamics when subjected to terrain inputs. The present version is a nonlinear two-dimensional model in the longitudinal and vertical directions. Two degrees of freedom (pitch and bounce) are associated with the vehicle hull with an additional degree of freedom associated with each roadwheel station on one side of the vehicle. Comparison of computer results with recent field test data show that the mathematical model accurately simulates actual vehicle dynamics.

77-1400

The Dynamic Characteristics of Automobile Seats with Human Occupants

J.H. Varterasian and R.R. Thompson

Research Labs., General Motors Corp., SAE Paper No. 770249, 12 pp, 9 figs, 14 refs

Key Words: Automobile seats, Human response, Ride dynamics

The dynamic characteristics of seated humans were measured in a laboratory environment. The seat/occupant system was excited vertically with random vibration. Relevant transfer functions were computed using real time acceleration signals fed to a Fourier Analyzer. The transfer functions describe the seat response, the human response, and the combined response in the frequency range from 2 to 20 Hz.

77-1401

Transient Aerodynamic Forces and Moments on Models of Vehicles Passing Through Cross-Wind

Y. Yoshida, S. Muto, and T. Imaizumi

Japan Automobile Research Inst., Inc., Japan, SAE Paper No. 770391, 16 pp, 27 figs, 10 refs

Key Words: Aerodynamic loads, Ground vehicles, Model testing

In the past, investigations of the dynamic performance of vehicles using scale models have rarely been attempted. This paper describes the experimental transient side forces and yawing moments on 1/10 scale models of vehicles passing through cross-wind region. From this study, it is clarified that the model experiment is an effective method in analyzing the dynamic behavior of vehicles in cross-wind.

77-1402

Dynamic Equilibrium of a Motor Vehicle in Oblique Air Flow (Rownowaga Dynamiczna Pojazdu Samochodowego Przy Skosnym Oplywie Powietrzem)

A. Nalecz

Polish Academy of Sciences, Warsaw, Poland, 65 pp (Jan 22, 1976)

(In Polish)

N77-14470

Key Words: Dynamic stability, Motor vehicles, Wind induced excitation

The state of dynamic equilibrium of a motor vehicle affected by lateral wind is presented. The state of equilibrium is defined by the Lagrange-Dirichlet theorem which can be used as a holonomic or nonholonomic system. These systems are compared. The dynamic model of a motor vehicle is described and equilibrium equations are derived. The forces and aerodynamic moments acting on the vehicle in lateral wind are discussed in detail.

77-1403

An Empirical Approach to Motorcycle Silencing

G.E. Roe

Simon Engrg. Labs., Univ. of Manchester, SAE Paper No. 770188, 16 pp, 18 figs, 7 refs

Key Words: Motorcycles, Noise reduction

This paper describes a simple inexpensive system of motorcycle silencing which has given successful results on prototype and production, touring and competition, 2-stroke and 4-stroke machines. Noise sources are identified and compared.

77-1404

Effects of Drawbar Properties on the Behavior of Articulated Vehicles

D.L. Taylor and T.R. Kane

Johns Hopkins Univ., Laurel, MD., ASME Paper No. 76-WA/Aut-10

Key Words: Articulated vehicles, Drawbars, Damping effects, Flexibility

Following a description of an articulated vehicle consisting of a towing vehicle and a trailer, linear differential equations are formulated and are used as a point of departure for the detailed study of complex frequencies characterizing small departures of the system from straight line motion.

ROTORS

(Also see No. 1306)

77-1405

Analysis of Torsional Vibration in a High Bandwidth Angular Position Servo

D.A. Keinholz and R.L. Piziali

Bell Laboratories, Whippany, NJ, ASME Paper No. 76-WA/Aut-9

Key Words: Torsional vibration, Rotors, Vibration tests, Finite element technique

The method of finite elements is used to predict the torsional vibration characteristics of the capstan rotor of an instrumentation tape recorder. The usefulness of such results in designing a high bandwidth servo is discussed. Comparisons of finite element predictions, with results of forced vibration experiments on an actual capstan rotor, are presented, and agreement is found to be satisfactory.

77-1406

The Vibration of Elastic and Viscoelastic Rotating Shafts

M.L. Badlani

Ph.D. Thesis, Univ. of Minnesota, 152 pp, 1976

UM 77-6929

Key Words: Shafts, Rotors, Rotor-bearing systems

A study of the dynamic behavior of elastic and viscoelastic rotating shafts is presented for the following cases: symmetric shaft in symmetric bearings; unsymmetric shaft in symmetric bearings; symmetric shaft in symmetric bearings -- non-linear problem; and unsymmetric shaft in unsymmetric bearings.

77-1407

Dynamics of an Elastic Seesaw Rotor

N. Kawakami

Fuji Heavy Industries, Ltd., Utsunomiya, Tochigi, Japan, J. Aircraft, 14 (3), pp 291-300 (Mar 1977) 13 figs, 6 refs

Key Words: Rotors, Equations of motion

A new method to analyze dynamic behavior of a seesaw rotor is presented. The derived equation of motion can be used to calculate the stability and performance of an elastic seesaw rotor by using Gessow's method which, prior to this study, has been limited to a nonelastic rotor. The equation of motion also includes the Blankenship method for calculation of the load distribution on a seesaw rotor in more refined form.

77-1408

The Coupled Flap-Lag-Torsional Aeroelastic Stability of Helicopter Rotor Blades in Forward Flight

M. Reyna-Allende

Ph.D. Thesis, Univ. of California, Los Angeles, 295 pp, 1976

UM 77-8530

Key Words: Helicopter rotors, Rotary wings, Aerodynamic stability

In this study a set of coupled flap-lag-torsional equations of motion capable of simulating general hingeless rotor blade configurations are derived. The equations are derived for the case of a rotor blade having moderate deflections (small strains, moderate rotations) thus the final equations of motion are represented by a system of coupled, nonlinear partial differential equations. The equations are capable of simulating rotor blades having: precone, droop, built in twist, distributed torsion, root torsion (or pitch link flexibility), blade root offsets and offsets between the elastic axis, aerodynamic center and the blade cross-sectional center of mass.

SHIP

(Also see No. 1291)

77-1409

On a Rectangular Pressure Distribution of Oscillating Strength Moving Over a Free Surface

H. Chen

R & D Div., American Bureau of Shipping, New York, NY, J. Ship Res., 21 (1), pp 11-23 (Mar 1977) 11 figs, 5 refs

Key Words: Surface effect machines, Ships, Hydrodynamic excitation

Through the application of linearized water-wave theory, a solution of the free surface due to the disturbance of a moving, oscillatory pressure distribution of rectangular form is obtained. Such a solution provides the basis for formulating the wave resistance of the moving pressure distribution just cited, as well as the hydrodynamic coefficients of a captured-air bubble of rectangular footprint in heave motion. Numerical methods are developed to compute the aforementioned resistance and hydrodynamic coefficients, the numerical examples of which are also presented.

SPACECRAFT

77-1410

Vibration Testing of the TE-M-604-4-IUE Rocket Motor (Thiokol P/N E 28639-03)

R.E. Alt and J.T. Tosh

Arnold Engrg. Dev. Center, Arnold Air Force Station, TN, Rept. No. ARO-VKF-TR-76-65, 294 pp (Dec 1976)

AD-A034 227/9GA

Key Words: Solid propellant rocket engines, Vibration tests, Periodic excitation, Random excitation

The NASA International Ultraviolet Explorer rocket motor (TE-M-604-4), a solid fuel, spherical rocket motor, was vibration tested in the Impact, Vibration, and Acceleration Test Unit of the von Karman Gas Dynamics Facility. The objective of the test program was to subject the motor to qualification levels of sinusoidal and random vibration prior to the altitude firing of the motor in the Propulsion Development Test Cell, Engine Test Facility. The vibration testing consisted of a low level sine survey from 5 to 2,000 Hz, followed by a qualification level sine sweep and qualification level random vibration. A second low level sine survey followed the qualification level testing. This sequence of testing was accomplished in each of three orthogonal axes.

77-1411

State Estimation and Parameter Identification of Freely Spinning Flexible Spacecraft

D.A. Johnson

Univ. of Louvain, Louvain-la-Neuve, Belgium, J. Dyn. Syst., Meas. and Control, Trans. ASME, 99 (1), pp 51-57 (Mar 1977) 5 figs, 7 refs

Key Words: Spacecraft, Parameter identification

This paper studies the attitude estimation of a flexible spacecraft using the noise-corrupted measurements provided by sensors. The flexibility of the system is expressed in terms of internal deformation modes, and only a limited number of the latter are kept in view of simplifying the model. The estimation method is based on the Extended Kalman Filter algorithm, using an augmented state vector which includes the unknown parameters of the system.

77-1412

Dynamic Response Analysis on Spacecraft Structures Based on Modal Survey Test Data Including Nonlinear Damping

M. Degener

Deutsche Forschungs- u. Versuchsanstalt f. Luft- u. Raumfahrt, Goettingen, West Germany, In: ESA Modal Survey, pp 25-36 (1976) (N77-16379)

N77-16383

Key Words: Spacecraft, Modal tests, Nonlinear damping

Theoretical and experimental methods to determine the dynamic response of a spacecraft to the loads acting at the structure during launch and mission are compared. As one of the possible methods the general procedure of dynamic response calculations on the basis of experimental data, measured in a modal survey test, is presented. Special emphasis is given to the importance of the nonlinear damping behavior, which must be taken into account for the dynamic response analysis.

77-1413

Dynamic Qualification of Spacecraft on the Basis of Measured Modal Characteristics

E. Breitbach

Deutsche Forschungs- u. Versuchsanstalt f. Luft- u. Raumfahrt, Goettingen, West Germany, In: ESA Modal Survey, pp 9-12 (1976) (N77-16379)

N77-16381

Key Words: Spacecraft, Modal analysis, Modal tests, Component mode synthesis

A brief introductory survey is given about the concept for the dynamic qualification of spacecraft structures utilizing modern modal techniques the several parts of which are specified within an operational flow diagram. Herein special attention is paid to the modal survey test, modal coupling and perturbation approaches and the dynamic response analysis on the basis of modal data. The meaning of these work packages is discussed in particular view of the dynamic optimization of spacecraft.

77-1414

Investigation of Spacecraft Vibrations by Means of the Modal Synthesis Approach

E. Breitbach
Deutsche Forschungs- u. Versuchsanstalt f. Luft- u. Raumfahrt, Goettingen, West Germany, In: ESA Modal Survey, pp 1-7 (1976) (N77-16379)
N77-16380

Key Words: Spacecraft, Component mode synthesis

Dynamic qualification of spacecraft requires a great number of experimental and analytical dynamic investigations. In case that a dynamic response analysis results in inadmissible amplifications and stress concentrations, the critical parts of the structure must be modified for instance by altering the mass distribution or by attaching additional damping and stiffness elements. Further problems arise when the dynamic properties of spacecraft are modified by additional elastic substructures coupled to a basic structure. All these problems can be solved by means of the so-called modal synthesis approach formulated in terms of normal mode characteristics. The fundamental physical relations of this approach were dealt with, and the range of applicability with special regard to spacecraft dynamics is pointed out. The efficiency of the modal synthesis approach is demonstrated for a typical problem of aircraft dynamics.

STRUCTURAL

(See Nos. 1236, 1268)

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TECHNICAL NOTES

R. H. Scanlan
On Earthquake Loadings for Structural Design
Intl. J. Earthquake Engr. Struc. Dynam., 5 (2), pp 203-205 (Apr-June 1977)

C. Filipich, P.A.A. Laura, and R.D. Santos
A Note on the Vibrations of Rectangular Plates of Variable Thickness with Two Opposite Simply Supported Edges and Very General Boundary Conditions on the Other Two
J. Sound Vib., 50 (3), pp 445-454 (Feb 8, 1977)
3 figs, 7 tables, 8 refs

P.A.A. Laura and C. Filipich
Fundamental Frequency of Vibration of Stepped Thickness Plates
J. Sound Vib., 50 (1), pp 157-158 (Jan 8, 1977)

W. Eversman
Initial Values for the Integration Scheme to Compute the Eigenvalues for Propagation in Ducts
J. Sound Vib., 50 (1), pp 159-162 (Jan 8, 1977)
2 tables, 1 ref

P.F.Y. Wong and N.W.M. Ko
Mass Transfer from Vibrating Cylinders
J. Sound Vib., 51 (2), pp 314-315 (Mar 22, 1977)
2 figs, 4 refs

L. Diez, C. Gianetti, P.A.A. Laura
Approximate Determination of the Lowest Cut-Off Frequency of a Square Coaxial Waveguide
J. Sound Vib., 51 (2), pp 311-313 (Mar 22, 1977)
2 figs, 7 refs

B.K.N. Rao
Some Studies on the Subjective Doubling of Low Frequency Whole-Body Vibrations
J. Sound Vib., 51 (2), pp 308-310 (Mar 22, 1977)
1 fig

B.K. Shivamogi
Uniformly Valid Mach Number Expansion of the Navier-Stokes Equations and Mathematical Formalization of Lighthill's Theory of Aerodynamically Generated Sound
J. Sound Vib., 51 (2), pp 303-307 (Mar 22, 1977)
6 refs

K. Kanaka Raju
Large Amplitude Vibrations of Circular Plates Carrying a Concentrated Mass
J. Sound Vib., 50 (2), pp 305-308 (Jan 22, 1977)
5 tables, 4 refs

CALENDAR

MEETING	DATE	LOCATION	CONTACT
	1977 JULY		
Application of New Signature Analysis Technology Conference	24-29	Rendge, NH	Dr. Sanford S. Cole, Engrg. Founda- Foundation Conf., 345 E. 47th St., New York, NY 10017 Tele. (212) 644-7835
	AUG		
Society of Automotive Engineers 1977 West Coast Meeting	8-11	Vancouver, Canada	SAE Hq., A. L. Weldy
	SEPT		
Vibrations Conference, ASME	26-28	Chicago, IL	ASME Hq.
	OCT		
NOISE-CON 77	17-19	Hampton, VA	Conf. Secretariat, Noise Control Foundation, P.O. Box 3469, Arlington Branch, Poughkeepsie, NY 12603 Tele. (914) 462-6719
48th Shock and Vibration Symposium	18-20	Huntsville, AL	H. C. Pusey, Director, The Shock and Vibration Info. Ctr., Code 8404, Naval Res. Lab., Washington, D.C. 20375 Tele. (202) 767-3306
	NOV		
Winter Annual Meeting, ASME	Nov 27 - Dec 2	Atlanta, GA	ASME Hq.
	DEC		
Sixth Turbomachinery Symposium	6-8	Houston, TX	Dr. M.P. Boyce, Gas Turbine Labs., ME Dept., Texas A & M, College Station, TX 77843
Acoustical Society of America, Fall Meeting	13-16	Miami Beach, FL	ASA Hq.
	1978 MAR		
Applied Mechanics Western and J.S.M.E. Conference	25-27	Honolulu, Hawaii	ASME Hq.
	APR		
Design Engineering Conference & Show, ASME	3-5	Chicago, IL	R.C. Rosaler, Rice Assoc., 400 Madison Ave., N.Y., NY 10017
Gas Turbine Conference & Products Show, ASME	9-13	London	ASME Hq.
Diesel & Gas Engine Power Conference and Exhibit	Apr 30 - May 4	San Francisco, CA	ASME Hq.

CALENDAR

MEETING	DATE	LOCATION	CONTACT
	1978 MAY		
Inter-NOISE 78	8-10	San Francisco, CA	INCE, W.W. Lang
IX Southeastern Conference on Theoretical and Applied Mechanics (SECTAM)	4-5	Nashville, TX	Dr. R.J. Beil, SECTAM, Dept. of Engrg. Sci. & Mech., Virginia Polytechnic Inst. & State University Blacksburg, VA 24061
Offshore Technology Conference	8-11	Houston, TX	SPE, Mrs. K. Lee, Mtgs. Section, 6200 N. Central Expressway, Dallas, TX 75206
Society for Experimental Stress Analysis	14-19	Wichita, KS	SESA, B.E. Rossi

CALENDAR ACRONYM DEFINITIONS AND ADDRESSES OF SOCIETY HEADQUARTERS

AFIPS: American Federation of Information Processing Societies
210 Summit Ave., Montvale, N.J. 07645

AGMA: American Gear Manufacturers Association
1330 Mass. Ave., N.W.
Washington, D.C.

AIAA: American Institute of Aeronautics and Astronautics, 1290 Sixth Ave.
New York, N.Y. 10019

AIChE: American Institute of Chemical Engineers
345 E. 47th St.
New York, N.Y. 10017

AREA: American Railway Engineering Association
59 E. Van Buren St.
Chicago, Ill. 60605

AHS: American Helicopter Society
30 E. 42nd St.
New York, N.Y. 10017

ARPA: Advanced Research Projects Agency

ASA: Acoustical Society of America
335 E. 45th St.
New York, N.Y. 10017

ASCE: American Society of Civil Engineers
345 E. 45th St.
New York, N.Y. 10017

ASME: American Society of Mechanical Engineers
345 E. 47th St.
New York, N.Y. 10017

ASNT: American Society for Nondestructive Testing
914 Chicago Ave.
Evanston, Ill. 60202

ASQC: American Society for Quality Control
161 W. Wisconsin Ave.
Milwaukee, Wis. 53203

ASTM: American Society for Testing and Materials
1916 Race St.
Philadelphia, Pa. 19103

CCCCAM: Chairman, c/o Dept. ME, Univ. Toronto, Toronto 5, Ontario, Canada

IEEE: Institute of Electrical and Electronics Engineers
345 E. 47th St.
New York, N.Y. 10017

IES: Institute Environmental Sciences
940 E. Northwest Highway
Mt. Prospect, Ill. 60056

IFToMM: International Federation for Theory of Machines and Mechanisms, US Council for TMM, c/o Univ. Mass., Dept. ME, Amherst, Mass. 01002

INCE: Institute of Noise Control Engineering
P.O. Box 3206, Arlington Branch,
Poughkeepsie, N.Y. 12603

ISA: Instrument Society of America
400 Stanwix St., Pittsburgh, Pa. 15222

ONR: Office of Naval Research
Code 40084, Dept. Navy, Arlington, Va. 22217

SAE: Society of Automotive Engineers
400 Commonwealth Drive
Warrendale, Pa. 15096

SEE: Society of Environmental Engineers
6 Conduit St.
London W1R 9TG, England

SESA: Society for Experimental Stress Analysis
21 Bridge Sq.
Westport, Conn. 06880

SNAME: Society of Naval Architects and Marine Engineers, 74 Trinity Pl.
New York, N.Y. 10006

SVIC: Shock and Vibration Information Center
Naval Research Lab., Code 8404
Washington, D.C. 20375

URSI-USNC: International Union of Radio Science - US National Committee c/o MIT Lincoln Lab., Lexington, Mass. 02173